LATE QUATERNARY PALAEOENVIRONMENTS OF THE SANDVELD, WESTERN CAPE PROVINCE, SOUTH AFRICA.

BY

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ABSTRACT

LATE QUATERNARY PALAEOENVIRONMENTS OF THE SANDVELD, WESTERN CAPE PROVINCE, SOUTH AFRICA

This thesis presents new palaeoenvironmental evidence from the semi-arid lowlands of the West Coast Sandveld, which prompts a fresh synthesis as to the nature of late Quaternary environmental changes in the southwestern Cape's fynbos biome.

The study is centred on Verlorenvlei, a remote coastal lake and swamp system which is ideally situated to investigate the complex interactions between late Holocene climate change, vegetation change, sea-level fluctuation, lacustrine/estuarine/fluvial sedimentology and human activity in the Sandveld region. In addition, this region of the West Coast has provided Quaternary scientists with a rich archaeological record against which independent lines of palaeoecological evidence can be evaluated.

In support of the study, a wide range of palaeoenvironmental techniques has been applied to sediments sampled from the Verlorenvlei area. Organogenic deposits have been radiocarbon-dated and subjected to pollen analysis and assorted sedimentological and geoarchaeological assessments. Preliminary fossil pollen data from Elands Bay Cave, assembled for the period following the Last Glacial Maximum until approximately the terminal Pleistocene, are suggestive of moister and possibly cooler conditions in the Sandveld at this time. This is in contrast to prevailing evidence from the summer rainfall region of the subcontinent. Particle size analysis and an assessment of the *in situ* fossil Mollusca from vibracores, derived from the estuarine reaches of Verlorenvlei, reveal substantive evidence for rapid sea-level fluctuations along the West Coast during the mid-Holocene. Further inland, several mid-Holocene higher sea-levels are reflected in the palynology of lacustrine cores derived from Grootdrift and Klaarfontein. Detailed pollen diagrams, presented from Grootdrift, Klaarfontein, Muisbosskerm and Spring Cave, reflect the regional vegetation history during several periods over the last 7 000 years. There is convincing evidence from these data that the first half of the Holocene - commensurate with the Holocene hypsithermal - was associated with reduced moisture availability, and hence arid conditions along the West Coast. By contrast, there is evidence from the latter half of the Holocene that conditions ameliorated in the Sandveld around 3 000 BP and that moisture was, at this time more freely available. Following a hiatus in sedimentation some time after 4 000 BP, marine conditions are no longer visible in Verlorenvlei, having been replaced by fresh water as the dominant hydrological regime. A high resolution palynological investigation of the Grootdrift wetland sediments has contributed to a detailed palaeolimnological reconstruction of the upper Verlorenvlei system since the time of colonial expansion into the area, some 300 years ago. The picture reveals a sequence of rapid ecological changes in the face of progressive human disturbance. Arising from these insights, a number of recommendations for the management of dryland aquatic ecosystems such as Verlorenvlei, are presented.

The significance of these late Quaternary palaeoenvironmental changes, in terms of the biogeography of plants and animals and also in terms of human occupation of the region, is examined. Although intra-regional contrasts are evident, it emerges that, for much of the later Quaternary and for large parts of the fynbos biome, precipitation may have fluctuated directly out of phase with climatic changes in the interior of the subcontinent. This situation has great relevance to the prediction of future climatic and environmental changes and their impacts on the southwestern Cape. The mid-Holocene hypsithermal event may provide a partial analogue for future biogeophysical changes that may be associated with the 'greenhouse effect'. The evidence from the Sandveld suggests that regional aridity, coupled with a rising sea-level, can be expected in the southwestern Cape and that fresh water, already in short supply in the region, will increasingly become a critical resource.

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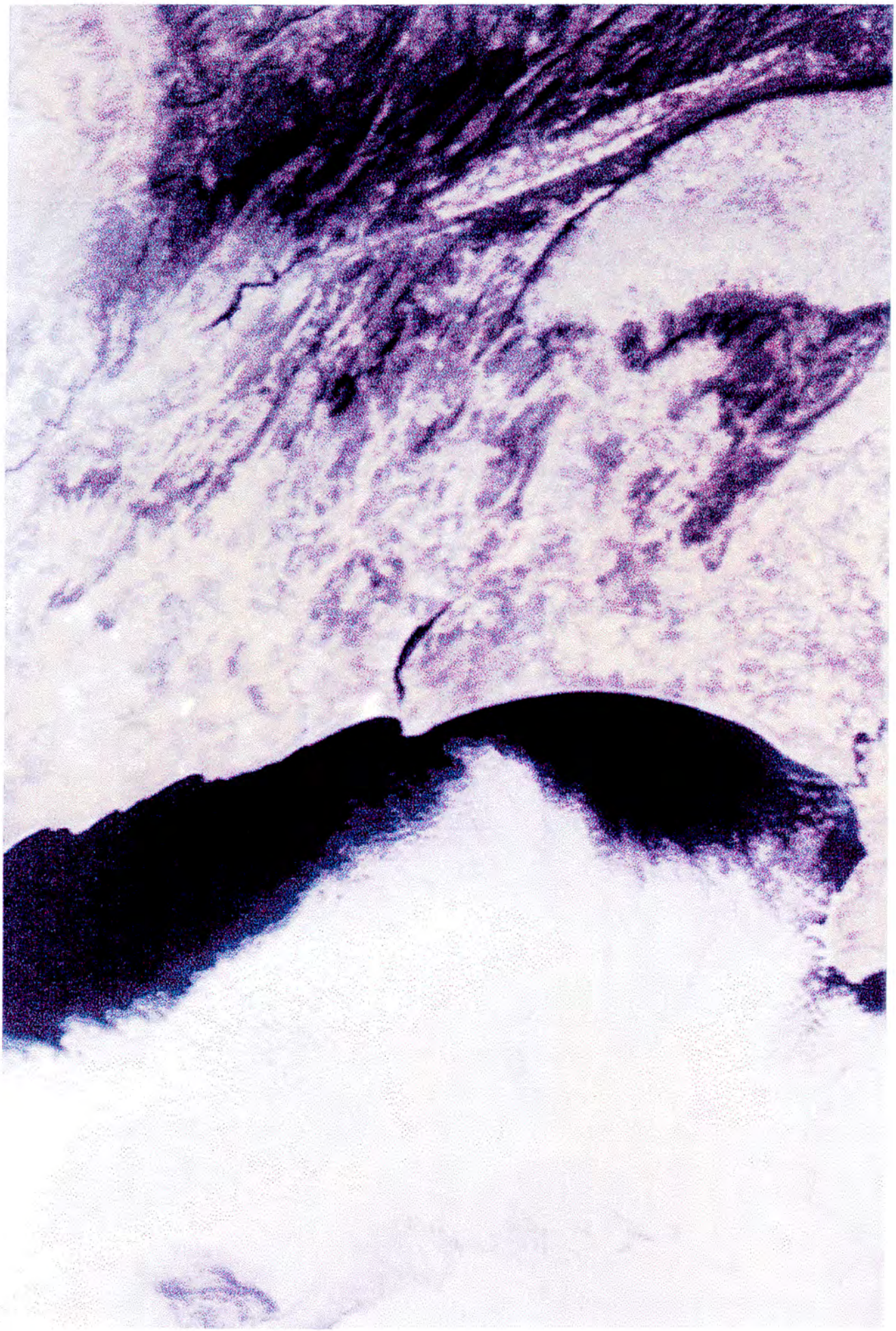

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I dedicate this work to my grandparents, Betty and Steve.

Frontispiece: Satellite image of the West Coast Sandveld and St Helena Bay. The promontory to the south of the picture forms part of the Vredenburg Peninsula, while Verlorenvlei is clearly visible in the centre of the photograph as a dark area inland of Cape Deseada. The Cederberg mountains and the Clanwilliam Dam are visible towards the eastern interior.

CONTENTS

Chapter 4 METHODOLOGY: QUATERNARY PALAEOECOLOGY

Chapter 5 TECHNIQUES IN MECHANICAL SAMPLING

Chapter 6 FIELD TECHNIQUES AND SAMPLING STRATEGIES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDICES

'To the dull mind nature is leaden. To the illuminated mind the whole world burns and sparkles with light.'

Ralph Waldo Emmerson

Chapter 1

INTRODUCTION

1.1 Introduction

As a result of the burgeoning human population and the suitability of lowland coastal environments for settlement, agriculture, and industry, coastal zones are under increasing threat from direct human impacts and indirect feedbacks which contribute to global change (in particular, climate and sea-level changes). Aggravated human impacts in coastal environments have resulted in severe ecological modifications of natural habitat and have seriously affected the diversity and stability of natural ecosystems. When viewed against the background of intensifying global change feedbacks, the long term environmental implications for coastal zones, not only for natural communities of plants and animals, but also for life-sustaining human resources, are distressingly uncertain. Recently, interest in Quaternary research has come to be focused on the reconstruction of local and regional palaeoclimatic and sea-level histories for coastal zone environments. Data based on palaeoenvironmental observations from these regions are critical for inclusion in various models used to predict climatic and oceanographic responses to global change, and contribute to an understanding of the underlying mechanisms.

1.2 Rationale in support of palaeoenvironmental research

Today, most members of the scientific community and the informed public concur with the findings of the *Intergovernmental Panel on Climate Change* (IPCC), which concludes that the envisaged global 'greenhouse' is a response to anthropogenic forcing, amplified by the impact of deforestation and the burning of fossil fuels since the industrial revolution (Houghton and Woodwell, 1989; Schneider, 1992; Roberts, 1994). The production of deleterious levels of 'greenhouse gases', among them carbon dioxide (CO_2), has so altered the chemistry of the atmosphere that unprecedented rates of climatic and environmental change have been forecast for the next century (Huntley, 1990a; Leggett, 1990; Ricklefs *et al.*, 1990). From studies conducted on past episodes of (natural) global change, the weight of evidence suggests that the rapidity of these human-induced changes might act to the detriment of natural populations of plants and animals, and especially, to sensitive and biogeographically insular ecosystems (Peters,

1988; Peters and Lovejoy, 1990; Huntley, 1991). In addition, the impacts of global change are expected to impart enormous economic and social disorder in those regions of the globe which are particularly sensitive to variations in climate and the effects of a wide range of human activities.

In response to these concerns, and in an effort to address the imminent problems expected to result from global climate change, the international scientific community, under the auspices of the *International Council of Scientific Unions* (ICSU), formally established the *International Geosphere-Biosphere Program* (IGBP) in 1986. The major scientific objective of the IGBP has been to: '...gain a quantitative understanding of the interactive physical, chemical and biological processes that regulate the Earth system and its capacity to support life' (IGBP, 1990, p 5). In 1988, the IGBP issued a special mandate for Quaternary studies, suggesting that there was a need for scientists to: '...document population, community and ecosystem responses to rapid environmental changes that occurred in the past in order to provide insight into the rates and directions of biotic changes that may occur in the near future...' (Delcourt and Delcourt, 1991, p 193). In 1992, the IGBP promulgated a new research initiative on *Past Global Changes* (PAGES), with a view to developing historical reconstructions of ecosystems and relating these to historical indicators of past conditions within the system (IGBP, 1992). Among the many research foci and activities set out for PAGES, the reconstruction of past changes in the coastal zone, among others, has been afforded high priority. In particular, the IGBP recommend that emphasis be placed on the study of coastal biogeomorphology, including sea-level transgressions and regressions, the assessment of past rates of sediment and peat accumulation, the analysis of dated intertidal and subtidal sediment cores, and the historical reconstruction of human-induced development, land use change in watersheds, and habitat alterations (IGBP, 1993).

Environmental changes can be reconstructed from various sources of geological and biological evidence, viz: alterations in lake- and sea-levels, geomorphological and archaeological evidence, micro- and macroscopic fossil remains as well as isometric methods such as radiometric dating (Goudie, 1992). Increasingly, multi-faceted, palaeoenvironmental investigations are being used as a retrospective method of elucidating the nature, rates and timing of former episodes of natural environmental change. More specifically, the historical analysis of the earth system, in terms of key environmental parameters such as: climate, terrestrial and aquatic ecosystems and human activity, can be used in the validation of predictive models that are used to simulate future climates (Delcourt and Delcourt, 1991; Huntley, 1990a). As a result of this newfound relevance, palaeoenvironmental research has emerged, in the 1990's, as one

of the major research priorities among the earth, atmosphere and biological sciences (Adams and Woodward, 1992; Meadows *et al.*, 1993).

The re-emergence and revitalisation of palaeoenvironmental research has not been without criticism. Pragmatists have been quick to highlight the various conceptual and methodological shortcomings of using the technique to provide analogues for the future (eg, Parry, 1985). While established techniques such as fossil pollen analysis have been widely applied in the quest to unravel the complexities of former climatic and environmental change (eg, Birks and Birks, 1980), there has been recent debate concerning the use of palaeobotanical evidence as a reliable tool to predict the influence of future (human-induced) global change (eg, Davis, 1990; Ricklefs *et al.*, 1990). The problems relate largely to the complexity of the relationship between climate and vegetation (refer to Hengeveld (1990) for a review), and highlight the fact that the notion of vegetation communities tracking their climatic optima as static assemblages is overly simplistic. There is growing evidence from palaeobiological facets of Quaternary research that lends support to concepts of individualism and dynamism among vegetation communities (Bond and Richardson, 1990; Graham and Grimm, 1990). These conclusions are reinforced by the fact that contemporary climate forcing mechanisms and rates of climatic change are very different from those of the past - as are the modern distributions of plants and animals - and it is possible that no appropriate palaeoanalogues exist in the past to adequately model rapid future changes. Furthermore, the general assumption that traditional non-industrial societies have had no significant impact on the natural environment is being increasingly challenged by new evidence to the contrary (eg, O'Hara *et al.*, 1994). These conceptual complications highlight the need for renewed emphasis to be placed on an improved understanding of the *mechanisms* that have accounted for contemporary patterns and processes, since it is these insights into the functioning of systems that will be most beneficial to an understanding of global change.

Despite the conceptual difficulties alluded to above, it is widely accepted that palaeoenvironmental research has already made significant contributions towards an appreciation of future global change. Huntley (1990b) notes some of the important contributions from palaeoenvironmental studies, especially those which elucidate pollen-climate relationships, which have, among others:

1. Enabled the determination of simplistic characteristics of past climates based on reliable fossil and geological indicators.

2. Established that climatic changes of the past varied spatially, directionally and in magnitude.

3. Verified that climatic gradients have changed through time, both in steepness and orientation.

4. Enabled the validation of predictive General Circulation Models (GCMs).

The next decade is likely to see major advances in both the scale and resolution of Quaternary palaeoenvironmental reconstructions. These insights from the past will increasingly benefit those responsible for future environmental planning and political decision making. As a result, neoecologists, conservationists, urban planners, agriculturalists, industrialists and politicians will be in a position to instigate timeous and appropriate environmental strategies for the future - not only for the sake of biotic diversity, but for the integrity of the entire earth-atmosphere-ocean system and all its inhabitants.

While studies of environmental change have been prolific from northern hemisphere temperate regions, the accumulation of evidence from the southern hemisphere has only recently gained impetus. Despite the increase in Quaternary studies in southern Africa, it remains apparent that rather little is known of the palaeoenvironments of the region, least of all from the extensive sub-arid and arid parts of the coastal lowlands of the southwestern Cape. In terms of the scientific objectives of the IGBP, which call specifically for the development of historical reconstructions in the coastal zone regions of the world, this study, centred on the West Coast *Sandveld* would seem to be well placed to make an important contribution to the local and global synthesis of palaeoenvironmental research.

1.3 The Sandveld: a brief biogeographical synopsis

Before considering the aims and objectives of the study, it is useful to discuss, briefly, the choice of study area and the contemporary biogeographical status of the Sandveld region. The Sandveld occupies the West Coast lowlands which separate the Atlantic Ocean along the western seaboard from the Cape Fold Belt mountains inland and to the east (refer to Figure 3.1). The West Coast region encompasses a great diversity of terrestrial and coastal landforms and vegetation types. Soil types are not especially variable in the Sandveld and the climate for the region is generally semi-arid. The Sandveld is thus considered an appropriate study area with which to illustrate the twin themes of climatically induced changes in terrestrial vegetation and the depositional and erosional history induced by fluctuating sea-levels of the Holocene.

1.3.1 Current land use and conservation in the Sandveld

The natural *Lowland Fynbos* and *Strandveld* vegetation types of the Sandveld, long renowned for their extraordinary levels of species richness (Goldblatt, 1978), are presently under threat from the burgeoning impacts of strip-cultivation, incessant crop rotation, overgrazing and the stranglehold of alien invasives (Hilton-Taylor and le Roux, 1989). While extensive tracts of 'natural' vegetation remain in areas of marginal agricultural importance along the coast, most are subject to the impacts of grazing, the wild flower trade and various recreational pursuits. There is only a handful of 'nature reserves' scattered throughout the Sandveld which offer protection to the endemic Sand Plain Lowland Fynbos and West Coast Strandveld. With the exception of the West Coast National Park, most of these 'reserves' are small, insular and privately owned (Jarman, 1986). Formal conservation measures in the region are thus recognised as being grossly inadequate (Boucher, 1983; Jarman, 1986), and as a consequence, as many as 60 plant species may already have been lost through extinction with a further 500 being threatened by human action (Bigalke, 1979). This scenario has serious ramifications for the maintenance of biotic diversity within the Sandveld, both floral and faunal. Since the arrival of European colonists in the region *circa* AD 1670, the large mammals have been systematically exterminated, a factor which is believed to have impacted on the natural regulation of vegetation ecology in the fynbos (Hendey, 1983). Unfortunately, there appears to be a perception among provincial and local government authorities that vast areas of 'undisturbed' natural vegetation remain in the Sandveld and this has contributed to complacency and a lack of conservation planning. This unsatisfactory state of affairs has provided impetus for one of the crucial research objectives of this study, namely: to evaluate the historical impact of progressive human disturbance on the natural vegetation of the Sandveld region.

Research in the Sandveld is centred around Verlorenvlei, a coastal lake system in a sensitive arid environment. The choice of Verlorenvlei has been influenced by the fact that it is situated within a small drainage basin with the potential to provide worthwhile information about purely *local* deposition and hydrological events in the Sandveld. The modern system, poised between fresh and saltwater conditions, represents a vital aquatic resource in the drylands of the Sandveld and has been identified as having enormous conservation importance - a situation which has prompted numerous well-substantiated motivations for the protection and management of the system (Grindley and Heydorn, 1979; Robertson, 1980; Jarman, 1986; Grindley and Grindley, 1987; Verlorenvlei Omgewingstaakgroep, 1993; Baxter and Davies, 1994). Although, the former South African Department of Environmental Affairs declared Verlorenvlei a wetland of

international importance under the *Ramsar Convention* in 1991, the area has yet to be formally conserved (South African Department of Environmental Affairs and Tourism, 1995; 1996). Increasingly, ecologists are of the opinion that the system, internationally renowned for its proliferation of waterbirds and diverse plant communities, may become irreparably damaged if conservation action is not rapidly forthcoming. To many members of the scientific community, and the public - including the national press (eg, Weekend Argus, 13 August, 1994) - it seems paradoxical that a wetland system with such a multiplicity of conservation assets should languish for so long without some measure of formal environmental control, and it is worth speculating, briefly, on possible reasons for this incongruity.

By virtue of its regional geography, Verlorenvlei has been spared many of the gross abuses suffered by similar wetlands in other parts of South Africa. The Sandveld has, until recently, revealed few strategic mineral deposits, and because the arid environment and depleted soils are hostile to agriculture, there has been little incentive for aggregated human settlement. At the local level, access to the wetland, and particularly to the open water embayment, has been restricted by a combination of private landownership and a lack of infrastructure. On the surface therefore, it would appear that Verlorenvlei has escaped the pressures of development and has consequently been spared the affliction of associated environmental impacts.

Since the Ramsar status of Verlorenvlei is unquestionably a response to vigorous lobbying by the scientific community, it is speculated that the absence of suitable local legislation for the protection and conservation of the system may be attributed to Verlorenvlei's deceptively pristine appearance. In other words, the lack of obvious environmental degradation has fostered the perception that Verlorenvlei is not, as yet, sufficiently threatened as to be eligible for statutory environmental control. Clearly, such a negligent approach to conservation - if this is indeed the case - is both undesirable and dangerous; - undesirable in the sense that it makes a mockery of the conservation ethic, and dangerous in that the environmental health of Verlorenvlei may, in the first instance, have been seriously misdiagnosed. This point will be illustrated more fully by an examination of the recent palaeohistory of the system, at a time when Verlorenvlei was indeed, for the greatest part, 'pristine'.

1.4 Aims and specific objectives of the study

An examination of the literature pertaining to the southwestern Cape (refer to Chapter 2) reveals that there remain a number of unanswered questions regarding the nature and significance of environmental change during the Quaternary period. The most fundamental questions concern the characteristics of the climate in the southwestern Cape, during the period spanning the Last Glacial Maximum through to the present day, viz:

1. What have been the most important characteristics of the regional climate during the late Quaternary insofar as it has responded to major global changes?
2. Has the region reacted in a spatially and chronologically consistent manner to late Quaternary environmental changes or are sub-regional variations apparent?
3. How will the region respond to future climatic change, especially assumed global warming?

The principal aim of this investigation is to reconstruct the nature, amplitude and timing of late Quaternary environmental change in the Sandveld, and to attempt to address the fundamental research questions posed above, in the context of the southwestern Cape as a whole. Particular attention will also be devoted to the role of human-intervention in the Sandveld landscape and the possible impacts on the environment, particularly with respect to the ecology of the region. The investigation assumes a broad-based multidisciplinary approach and draws on wide-ranging evidence from diverse sources such as palynology, sedimentology, palaeolimnology, estuarine palaeoecology, coastal geomorphology, geoarchaeology and historical records. Research is focused around the site of Verlorenvlei, since the wetland environment offers a number of advantages in terms of its physiography and lacustrine-estuarine status, viz:

1. The upper reaches of the Verlorenvlei wetlands are expected to yield fluvial-lacustrine deposits, including pollen-bearing sediments that span the Holocene and possibly extend back to the Last Glacial Maximum.
2. Verlorenvlei is juxtapositioned along an important ecotonal boundary separating the fynbos and Strandveld vegetation types of the southwestern Cape from the karroid communities of Namaqualand and the Karoo (Sinclair *et al.*, 1986; Acocks, 1988). Environmental fluctuations, anticipated for the terminal Pleistocene and

Holocene, are expected to result in alterations in the proportions of fynbos and karroid taxa in the fossil pollen record of Verlorenvlei.

3. The lower reaches of the Verlorenvlei system, partially isolated from the sea today, are known to have experienced greater marine interaction during the mid-Holocene (Yates *et al.*, 1986). The sequence of transgressive and regressive marine events from this period should therefore be recorded in the sediments of Verlorenvlei as a series of interdigittating fluvial-lacustrine and estuarine contacts.

4. There is a rich human-cultural record preserved in the archaeological cave sequences around Verlorenvlei. A wealth of geoarchaeological and 'proxy' palaeoenvironmental evidence has contributed to a number of assumptions regarding the nature and timing of environmental change along the West Coast during the late Quaternary and especially the mid-Holocene. Since many of these assumptions are controversial (they remain untested against the palaeorecord), they provide a useful basis against which the results and interpretations of this thesis can be compared and evaluated.

The investigation proceeds by means of a detailed examination of the fossil pollen record of past vegetation assemblages from a range of dated sedimentary deposits in and around Verlorenvlei. Complimentary sources of palaeoenvironmental information are gleaned from the sedimentary record preserved within the estuarine reaches of the system. In particular, information relating to sea-level changes during the Holocene, and lake-level fluctuations during the colonial period, is examined. Multiple hypotheses relating to the biogeographical history of Verlorenvlei are introduced under appropriate sections in the introductory chapters of this thesis. The information gained from the palaeorecord is used in the evaluation of these different assumptions.

Some of the more specific research objectives of the study are:

1. To augment the existing collection of contemporary reference pollen from the southwestern Cape through the sampling of herbarium specimens collected from the Sandveld region.

2. To establish the nature of modern vegetation-pollen relationships in the Sandveld through an analysis of the contemporary pollen rain captured in surface traps and preserved in recent surficial sediments.

3. To compare and evaluate a range of coring methodologies in an effort to establish the most appropriate technique for securing minimally-disturbed continuous sediment cores from the Verlorenvlei wetlands.

4. To conduct an extensive coring programme in and around the Verlorenvlei valley in order to locate sites with appropriate organic sediments.

5. To examine the stratigraphy and sedimentology from a series of sediment cores and archaeological sections and to obtain radiocarbon dates from basal stratigraphies and other suitable organogenic horizons.

6. To conduct detailed fossil pollen analysis from selected Sandveld sites and to reconstruct the late Quaternary vegetation history for the region.

7. To assess and measure statistically the correlation indices between the modern and fossil pollen records in order to identify possible analogue vegetation communities.

8. To evaluate, compare and seek stratigraphic and temporal correlations between the respective palynological and sedimentological records from the Sandveld.

9. To infer the sequence of climatic and environmental changes that occurred in the region during the period of deposition.

10. To establish whether the envisaged late Quaternary climatic changes have been of sufficient magnitude to induce the waxing and waning of vegetation communities across the Sandveld ecotone.

11. To determine if the present distributions of isolated Afromontane Scrub Forest elements are relict outliers of a former more widespread distribution or whether they are in fact recent arrivals in the Sandveld.

12. To consider the sedimentary and fossil pollen evidence from Verlorenvlei in terms of possible sea-level fluctuations that are postulated to have occurred along the West Coast during the Holocene.

13. To seek, in the palaeoenvironmental record, possible explanations that might account for the enigmatic disappearance of hunter-gatherer populations from the Elands Bay region during the mid-Holocene.

14. To evaluate the history of human disturbances in the landscape, through an assessment of the relative impacts of indigenous prehistoric communities, colonial settlers and modern farming communities respectively.

15. To reach conclusions about the late Quaternary environmental change in the Sandveld, and specifically Verlorenvlei, and to make suggestions regarding:

    i) future management and conservation strategies and,
    ii) future research objectives.

In order that the study be placed in an appropriate philosophical context, it is necessary to review the existing evidence for environmental change in southern Africa. This important critique is reserved for discussion in Chapter 2. A detailed description of the contemporary ecology and biogeography of the Sandveld and Verlorenvlei follows in Chapter 3. Chapter 4 discusses the general philosophical considerations relating to Quaternary studies and outlines the specific methodological approach used in support of this study. Chapter 5 provides a detailed technical account of the vibracoring technique while Chapter 6 outlines the physical sampling methodology in respect of the different sites. Laboratory techniques and details on the statistical treatment of the quantitative data are outlined in Chapter 7. The results and palaeoenvironmental reconstruction are presented together in Chapter 8. Final conclusions and recommendations are synthesised in Chapter 9.

Chapter 2

ENVIRONMENTAL CHANGE IN SOUTHERN AFRICA

2.1 Introduction: environmental change in perspective

With the approach of the conclusion of the second millennium AD, there is mounting concern regarding human-induced environmental changes and the effects that these will have on the biosphere. Among others, these changes include: global warming and climate change, ozone depletion and sea-level rise, deforestation and accelerated soil erosion - all of which are inextricably linked to the inexorable decline in biological diversity. Although consensus holds that such environmental permutations are being fueled as a consequence of population growth and the by-products of industrialisation (Leggett, 1990; Peters, 1992), environmental changes, *per se*, are by no means limited to these recent human-induced interventions. Throughout the geological history of the earth, naturally regulated climatic and environmental changes within the atmosphere, oceans and continents, have served to shape our planet during the course of its 4 600 million year evolution (Goudie, 1992). This inevitable and relentless form of dynamic global restructuring would seem to operate at every scale - from subtle shifts in local microclimate to substantial, earth-shattering volcanic and tectonic upheavals. Natural environmental change, as with biological evolution - on which it is known to have such a profound effect (eg, Burrows, 1990) - is governed not by humanistic conventions of orderliness and predictability but rather by patterns of randomness, uncertainty and episodic timing. Fossil records bear testimony to periods of relative environmental equilibrium followed by punctuated bouts of global upheaval, giving rise to episodes of enhanced speciation or, in some instances, wholesale extirpation (Stanley, 1979).

The driving mechanisms behind these natural environmental changes are both complex and poorly resolved. For example, the primary mechanisms put forward to account for climatic change have been attributed to various extra-terrestrial processes such as quasi-periodic variant astronomical cycles (Tyson, 1986; Lindesay, 1990) - commonly termed Croll-Milankovitch forcing - and to a range of internal geosphere-atmosphere interactions of which fluctuations in the concentration of atmospheric CO_2 is considered the most crucial (Delmas, *et al.*, 1980; Jouzel *et al.*, 1987; Huntley and Webb, 1989). Since the relationship between all living organisms and prevailing climate has been tightly defined (Peters, 1988; Burrows, 1990; Davis, 1990; Huntley, 1990a; 1991), climate change is considered to be a central element in determining the composition

and distribution of biota and the restructuring of landscape geomorphology (Goudie, 1992). Modern vegetation distributions (and to some extent edaphic continuity) frequently coincide with climatic regions and this presupposes that any change in the climatic regime will obviate either a response in the distribution (eg, migration) or the composition (eg, evolutionary adaptation) of the impacted biota (Emanuel *et al.*, 1985; Davis, 1990). The evidence used in support of environmental change is frequently biogeographical in nature and serves to reinforce the perception that plants and animals are continually having to adjust their particular ranges in response to fluctuating environmental conditions. There is an inherent danger of tautology (circular argument) attached to such palaeoenvironmental interpretations, in that one line of evidence may be used to retrodict a particular environmental oscillation, which, in turn, is used to support evidence for changing distribution patterns among *other* species (refer to Stott (1981), for a discussion on this topic). Nonetheless, the discretionary application of established palaeoenvironmental techniques, such as fossil pollen analysis, in the reconstruction of former vegetation communities, has proved instrumental in advancing our knowledge and understanding of the dynamics of natural environmental change. In turn, these insights have shed new light on pressing contemporary issues such as the contribution of human impacts to the current climatic and environmental trends and the predictability of future environmental changes.

While the last two thousand years and, perhaps even more importantly, the last two hundred years, will be remembered for the manner in which our own species has become arguably the dominant agent of environmental change, the preceding two million years of earth history are recognised for the important role that natural environmental change has had in the evolutionary development of all modern fauna and flora including, paradoxically, that of *Homo sapiens sapiens*. Probably the most compelling reason for studying the Quaternary Period, therefore, may be attributed to our intuitive inquisition, as humans, to decipher and reconstruct the environmental history of that period for which the evolutionary and social development of our own kind appears to have been so profound. This inherent anthropocentric bias notwithstanding, there are a number of other significant reasons why environmental research has come to be focused on this comparatively brief period of geological time. Of great importance is the fact that global climates of the last two million years have produced a regime that has oscillated between full glacial and full interglacial phases, and the earth appears to have experienced almost as great a range of climatic and environmental variability as that which occurred throughout the entire preceding earth history (Goudie, 1992). Furthermore, as with our own species, modern biotic communities of fauna and flora first

began to assemble during the Quaternary and, progressively, modern distribution ranges first began to emerge (Delcourt and Delcourt, 1991).

Despite the attraction of the earlier Quaternary Period as an obvious research 'frontier', many palaeoenvironmental studies (including most fossil pollen studies) have focused their attention on the late Quaternary or that period comprising the terminal Pleistocene (*circa* 40 000 to 10 000 years ago) and the Holocene (10 000 years ago to the present day). There are a number of significant reasons for this pre-occupation with the late Quaternary Period. Of the many climatic oscillations that are known to have punctuated the Quaternary (Hays *et al.*, 1976; Imbrie and Imbrie, 1979; 1980) the most recent glacial-interglacial cycle is undoubtedly the most important with respect to the structure and functioning of present-day terrestrial and aquatic ecosystems (Birks, 1986). Furthermore, conventional radiocarbon dating - which is universally applied and widely accepted as an appropriate technique in the derivation of reliable age-estimates for organic deposits - has an age-accuracy limit corresponding to ~ 40 000 years. (To some extent this limitation has been overcome by recent advances in accelerated mass spectrometry (Pilcher, 1991; Hedges, 1991) that have extended the limits of radiocarbon dating by a further 20 or 30 000 years in certain instances). A less obvious, but no less important consideration concerns the problematical role played by biological evolution over so-called evolutionary time scales (Delcourt and Delcourt, 1991). Additional factors which support the application of pollen studies from the late Quaternary include: the abundance of organic, pollen-rich sites that have been actively accumulating since the onset of environmental amelioration following the Last Glacial Maximum (*circa* 18 000 BP) and the accelerated impact of humans on global vegetation, particularly in response to pastoralism and agriculture during the Holocene (Goudie, 1981).

The Quaternary environmental history of the temperate latitudes in the northern hemisphere is relatively well established due to the development and refinement of techniques such as pollen analysis (Fægri *et al.*, 1989). Such techniques have come to be applied throughout the temperate and tropical regions of the world and today there is a growing body of global evidence which illustrates the nature of environmental change (eg, Goudie, 1992). By comparison, the application of similar techniques in sub-humid and arid regions of the world has not been quite so enterprising and this has contributed to spatial imbalances in the scale and resolution of studies investigating Quaternary environments. More recently, with the expansion of scientific exploration into areas hitherto neglected (notably parts of South America, Africa, India, and Antarctica), the elucidation of past environments is progressively becoming more widespread.

The review which follows aims to address, briefly, the evidence for environmental change which is accumulating from southern Africa. Attention focuses specifically on the evidence from the southwestern Cape and the changes which are envisaged to have occurred in this region during the late Quaternary (from the Last Glacial Maximum onwards). Consideration is also given to the geoarchaeological evidence that has accrued from the Verlorenvlei region of the Sandveld for the same time period.

2.2 Evidence for environmental change in southern Africa

Following the bouts of tectonic activity and pronounced upliftment which occurred during the Tertiary (Partridge and Maud, 1987), the geological history of the southern African subcontinent has been characterised by relative stability during the Quaternary. As a consequence, erosion rather than deposition has been the predominant geomorphological process acting in the Quaternary landscape (Dardis and Moon, 1988). This factor, combined with strongly seasonal climates, widespread aridity and variable soil pH has generally acted against the formation and preservation of organogenic deposits. Despite the physical limitations imposed by the hostile southern African environments, the Quaternary interpretations invoked by van Zinderen Bakker (1955; 1957), Coetzee (1967) and van Zinderen Bakker (1976) were among the first reports on palaeoclimatic and palaeoenvironmental changes based on evidence that included ecological and biological indicators. For the most part, however, palaeoenvironmental research in southern Africa has traditionally been the domain of the geological sciences and archaeology (eg, Butzer, 1984a,b; Deacon *et al.*, 1984; Rust *et al.*, 1984; Partridge, 1985). More recently, Meadows (1988a) and, subsequently, Harwood (1994) have identified spatial and temporal patterns of organic accumulations in the subcontinent, based on the assimilation and analysis of published radiocarbon dates from 41 southern African sites. The records show (Meadows, 1988a; Harwood, 1994) that studies involving organic accumulations have contributed to a steady increase in the use of biological indicators as evidence for environmental change in southern Africa. In fact, it can be argued that organogenic deposits and their incumbent fossils have produced some of the most unequivocal evidence surrounding the scale and timing of late Quaternary climatic changes in the subcontinent (eg, Deacon and Lancaster, 1988).

In recent years, spurred on, perhaps, by the climate change revelations arising out of the Vostok ice core from Antarctica (Jouzel *et al.*, 1987), there has been a marked increase in the number of Quaternary palaeoenvironmental reconstructions from the southern hemisphere. Meadows *et al.* (1993) reflect on the growth of Quaternary studies

in southern Africa and attribute the upsurge to a growing realisation that an understanding of past environmental changes is an important key to making more accurate predictions as to the nature of environments of the future. Tyson (1993) reports on the South African Global Change Programme (affiliated to the IGBP 'PAGES' programme) which draws on palaeoenvironmental evidence to reconstruct the climates of southern Africa for the past 2 000 years. In turn, these data are used to aid in the construction of GCMs to simulate how the subcontinent's climates are likely to change over the next 50 years. From the many diverse lines of evidence now under investigation, patterns of late Quaternary environmental change in the subcontinent are slowly beginning to unfold, as witnessed by the publication of two edited volumes (Klein 1984; Vogel, 1984), and the extensive reviews by Tyson (1986), Deacon and Lancaster (1988) and Partridge *et al.* (1990). Not unexpectedly, these reviews fail to achieve outright consensus in their respective interpretations, partially due to the variability among sources of inter-regional evidence and partially due to the lack of concordance among researchers in their interpretation of the same, often limited, data. However, despite interpretative complexity and discordance, one mutual theme which does arise out of these three syntheses, is the recognition that different regions within southern Africa have responded uniquely to the global changes that have characterised the last 20 000 years.

With the increasing spatial and temporal resolution of palaeoenvironmental studies from southern Africa, greater emphasis has, therefore, come to be placed on regional interpretations of biogeographic range and ecosystem history (eg, Linder *et al.*, 1992). In addition, the regional palaeodata provide a useful basis against which to evaluate the authenticity of climate models that have been put forward to account for changes in synoptic climatology in the subcontinent. Figure 2.1 provides a convenient, albeit highly simplistic, graphical summary of Cockroft *et al.*'s (1987) synthesis, the most recent and comprehensive in a series of subcontinental climate models (refer to Nicholson and Flöhn (1980), Harrison *et al.* (1984) and Tyson (1986) for additional discussion on climate models). The Cockroft *et al.* model reflects a spatial synthesis of changing climatic conditions between 25 000 and 4 000 BP, across southern Africa. A descriptive summary of the model has been undertaken by Tyson (1986) from which the following major observations are noted:

1. At the time of the Last Glacial Maximum, temperatures were consistently lower by between 5 and 8° C throughout the subcontinent (Talma *et al.*, 1974; Vogel, 1983). High mountain regions, notably the Drakensberg, Lesotho and the Cape Fold Belt experienced periglacial activity (Lewis and Dardis, 1985; Boelhouwers, 1991), but at no time did true glacial conditions prevail in southern Africa.

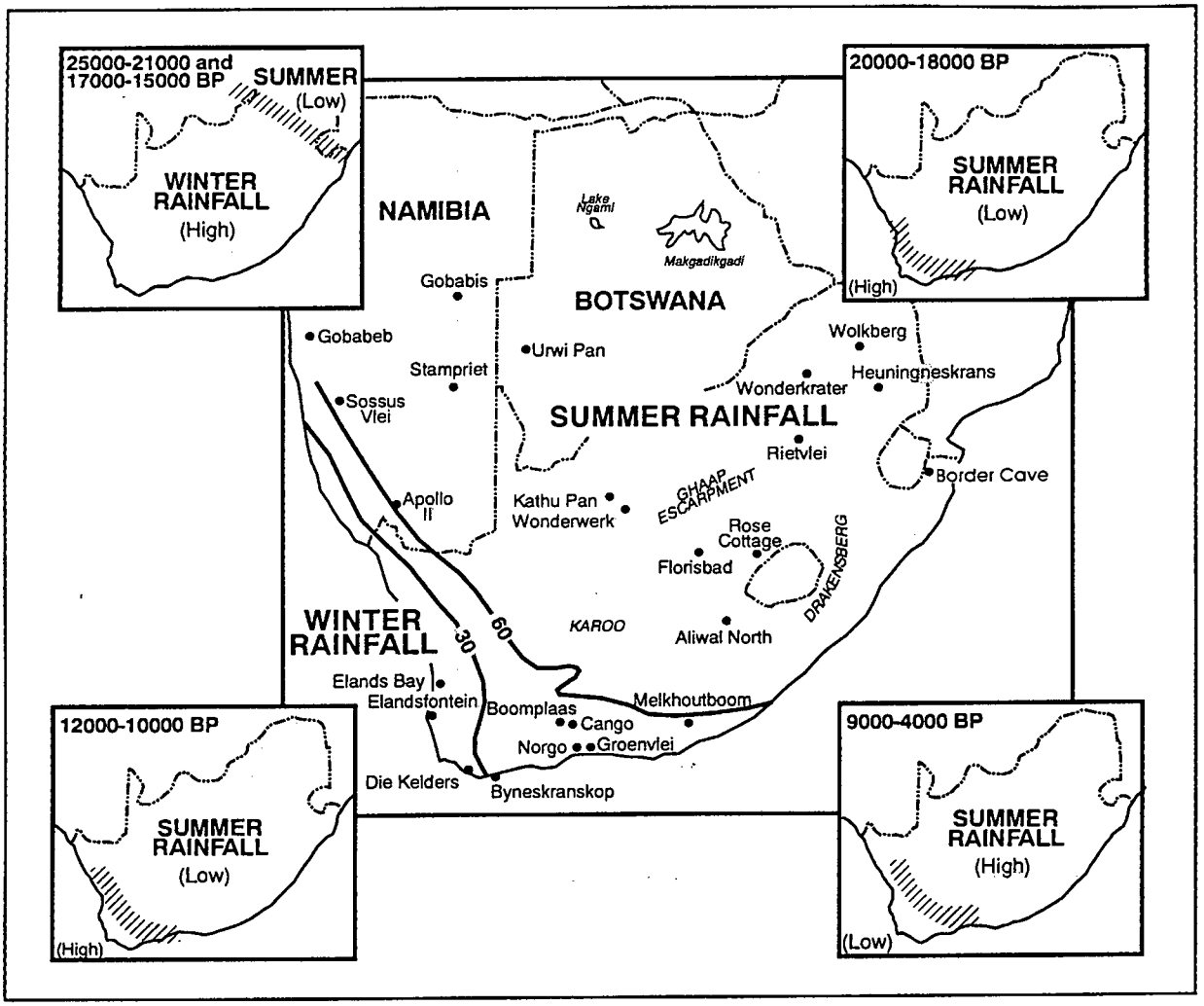


Figure 2.1 Climatic model of the regional rainfall variation in southern Africa. This shows the present-day distribution, and summer and winter rainfall regions in southern Africa (isolines give percentage annual rainfall received in summer), together with hypothesised positions of the summer-winter rainfall boundary at different times of the year. After Cockroft *et al.* (1987).

2. The climate of the Last Glacial Maximum was dominated by an enhanced El Niño / Southern Oscillation (refer to Deacon and Lancaster (1988) for a detailed explanation) during which westerly winds and cyclones would have been drawn northwards, potentially increasing precipitation in the winter rainfall region, while simultaneously inducing conditions of drought in the summer rainfall region.

3. The dynamics of the Southern Oscillation are such that during periods of higher temperature, variations in the zonal Walker Circulation are thought to bring about a reversal in the regional rainfall patterns. Such is the case anticipated for the post-Glacial period (16 000 - 12 000 BP) when temperature amelioration and increased moisture appear to have characterised much of the interior of southern Africa (Tyson, 1986). Curiously, there is no evidence to suggest that the winter rainfall region of the southwestern Cape was more arid during this post-glacial phase. In contrast to the model, evidence from Cape Hangklip (Schalke, 1973) and the

Cederberg (Meadows and Sugden, 1990; 1991a) suggests that climates in the southwestern Cape, as with the interior of southern Africa, were both moist and cool towards the terminal Pleistocene.

4. A period of pronounced desiccation, centered abruptly around 11 000 - 10 000 BP, and lagging behind the rest of the African continent by about 2 000 years (Street and Grove, 1976), seems to have characterised most of the interior of southern Africa during the transition from terminal Pleistocene to early Holocene. That this phenomena corresponds, temporally, with the minor glacial readvancement of the Younger Dryas in the northern hemisphere, suggests that the perturbation may have been of global significance (Goudie, 1992).

5. Following the commencement of the Holocene (10 000 - 5 000 BP), there is incongruous evidence from the summer rainfall region. While the central and western regions of the subcontinent experienced an amelioration to wetter conditions, the eastern parts, apparently, remained dry. Intra-regional variability appears also to have characterised the southwestern and southern Cape; however, the gross interpretation is that these regions were experiencing greater aridity and were therefore climatically 'out of phase' with the eastern parts of southern Africa. There is general consensus that during this time period temperatures were elevated and that it was warmer throughout southern Africa than the present day (Tyson, 1986). These findings also correspond with the global picture of a so-called Climatic Optimum (hypsithermal) operating between 6 000 - 4 000 BP (Goudie, 1992).

Although Cockroft *et al.* (1987) do not allude to the climates of the last 4 000 years in their model, the pattern of climatic change in southern Africa appears somewhat more resolved for this time period (eg, Deacon and Lancaster, 1988). Organic stratigraphic data, from across southern Africa, have accumulated in support of a moister period commencing between 5 000 - 3 000 BP. Palynological evidence (eg, Scott, 1984; Bousman *et al.*, 1988; Meadows and Sugden, 1990), supported by trends in the temporal distribution of radiocarbon dates (Meadows, 1988a), suggest a widespread return to wetter conditions after about 3 500 BP. Exceptions to this pattern exist at Wondercrater (Scott, 1982) and Rietvlei (Scott and Vogel, 1983) in the northern interior, and at Dunedin (Meadows and Meadows, 1988) in the eastern Cape. It is therefore clear that temperature and especially rainfall patterns are not consistent between the summer and winter rainfall regions and, as such, the spatial trends for the late mid-Holocene remain somewhat enigmatic. Low level temperature fluctuations have characterised the last 3 000 years (Deacon and Lancaster, 1988) with a gradual cooling trend observable as a global phenomenon (Tyson, 1986).

Reliable evidence concerning the climates of the past two millennia in southern Africa have proved difficult to assemble, partly due to the lack of correlation between different forms of proxy evidence and partly due to the fact that human interactions in the landscape have been so profound during this period. Tyson and Lindesay (1992), in their comprehensive evaluation of wide ranging evidence, believe there is a general relationship between southern African and global climatic trends for the same period. (Moderate warming from AD 900 to 1300 is consistent with the timing of the Medieval Warm Epoch in the northern hemisphere). This period was followed by a bout of pronounced cooling from AD 1300 to 1850 (Tyson, 1986), generally regarded as the Little Ice Age. A return to warmer conditions after about AD 1800 appears also to be a global trend but whether this is a natural phenomenon or a consequence of anthropogenic global warming remains unclear (Tyson and Lindesay, 1992).

The collective sum of evidence for late Quaternary climatic and environmental changes in southern Africa remains deficient by comparison to subcontinental studies in Europe and America. It is widely accepted that the scarcity of chronologically fixed sequences has led to palaeoenvironmental studies which are spatially disjunct and frequently intermittent. Even within regions, such as the southwestern Cape, the handful of palynological studies has come to be concentrated in areas of localised moisture, especially boggy sites in proximity to the Cape Fold Mountains. It is reasonable to assume that these sites have been carefully selected as a consequence of their contemporary climatic and edaphic regime, and if so, then the emergent patterns in the late Quaternary environmental history of this region are open to further interpretation. Accordingly, the emphasis of this review will be to consider the prevailing late Quaternary evidence that has accrued from sites within the southwestern Cape. It is expected that such an approach will satisfy dual purposes. Firstly, it will highlight the regional palaeoenvironmental trends that have been established for the southwestern Cape and, secondly, it will allow for comparisons to be drawn between the existing patterns and those (potentially new) trends which are expected to arise out of the Sandveld study.

2.2.1 Late Quaternary environmental change in the southwestern Cape

An examination of the evidence for late Quaternary environmental change in the southwestern Cape region requires a brief biogeographical introduction (refer to Chapter 3 for a more comprehensive account). At the southwestern tip of Africa, a

Mediterranean-type climate, coupled with a particular combination of geology, topography, soils and environmental and cultural history, has resulted in a distinctive landscape characterised by a unique vegetation formation. Perhaps more than any other feature of the natural environment, this species-rich and prolifically biodiverse vegetation-type, known as *fynbos*, is what distinguishes the southwestern Cape from other regions in southern Africa (Cowling , 1992). Since 1980, three major Quaternary environmental syntheses, all of which include attempts at regional interpretations, have been published, viz: Deacon *et al.* (1983), Deacon and Lancaster (1988) and Partridge *et al.* (1990). All three offer an integrated and multi-disciplinary picture of changes within regions over time, and provide analyses which suggest strongly developed differences between the southwestern Cape and the rest of southern Africa with respect to the development of Quaternary palaeoenvironments. In reviewing each of the abovementioned syntheses, emphasis is placed on establishing the broader pattern of environmental change and, in particular, revealing the characteristic environments interpreted for i) the Last Glacial Maximum (assumed to have centered around 18 000 BP), and ii) for the duration of the Holocene (ie the last 10 000 years). This review also focuses on additional palaeoenvironmental features regarded as significant, and considers aspects of the palaeoenvironments that compare or contrast with contemporaneous changes elsewhere in southern Africa.

Deacon *et al.* (1983). This is not so much a single synthesis as a collection of separate reviews based on different forms of palaeoecological evidence such as large mammals (Klein, 1983), small mammals (Avery, 1983) and pollen (Coetzee *et al.*, 1983). The most comprehensive set of data, in as much as they relate to the greatest number of individual sites, emanates from Klein's (1980; 1983) reviews of the large mammal fossils found at 31 localities distributed across the biome. Using evidence from Nelson Bay Cave, Byneskranskop 1, Buffelskloof and Boomplaas, which are regarded as falling within the fynbos biome proper, together with the evidence from Elands Bay Cave and Melkhoutboom Cave just beyond its northwestern and southeastern margins respectively, Klein (1980; 1983) draws the important conclusion that the period of time coincident with the Last Glacial Maximum was characterised by the dominance of large grazing, as opposed to browsing, mammals. Such a situation is consistent with grasslands developed across large expanses of what is currently fynbos vegetation. Climatic conditions at this time are interpreted by Deacon *et al.* (1983) to have been both cooler and more moist than those which presently prevail. Micromammalian evidence does not always accord with this view; at Boomplaas, for example, Avery (1983) suggests that the Last Glacial Maximum period, which is characterised by reduced diversity, was considerably cooler and *drier* than at present, a conclusion which points to the notion that environmental

changes in the fynbos were '...not necessarily regionally synchronous or comparable throughout the biome' (p 152) and thus emphasises '...the need for caution in finding an acceptable and meaningful level of generalisation or extrapolation from the evidence' (p 152). The pollen evidence (Coetzee *et al.*, 1983) is uninformative for the Last Glacial Maximum period, which is probably not represented in the polleniferous sites sampled. An issue which is not adequately addressed in the Deacon *et al.* (1983) publication is the palaeoenvironmental indicator value of 'grassiness' in the fynbos context; the climatic signal of such an observation is interpreted variously as indicative of 'cooler and moister' (Klein, 1983) and 'cooler and drier' (Avery, 1983). This conundrum remains unresolved, not least because there are no analogues for such a situation in the modern biome, except perhaps the grassy fynbos of the eastern parts of the region which prevails under an all-year precipitation regime.

Palaeoecological evidence for the Holocene is considerably more abundant. Large mammal fossils indicate conditions broadly similar to those of today for the last three to five thousand years, and that the earlier part of the Holocene was somewhat warmer and drier (Klein, 1983). Micromammals at Boomplaas (Avery, 1983) are consistent with this suggestion of an early Holocene drier than today, although sites elsewhere within the biome suggest a much more complex sequence of climatic fluctuations during the Holocene. Pollen evidence available to Coetzee *et al.* (1983) was restricted to the studies of forest and fynbos development in the coastally-situated Wilderness Lakes of the southern Cape (after Martin, 1968) and the chronologically problematic studies of Schalke (1973) in the southwestern Cape. Very little consistency is apparent between these studies, in part because they deal with different time periods and in part because they are in ecologically distinctive regions.

The Deacon *et al.* synthesis reveals that there is more discordance than concordance between late Quaternary palaeoenvironmental reconstructions based on different forms of evidence. Explanations as to the reasons for such discordance relate to the possibility of inter-regional variations in climatic response, although the general paucity of evidence coupled with the likelihood that different ecosystem components may respond differentially to environmental change cannot be ruled out.

Deacon and Lancaster (1988). Although written five years later, the Deacon and Lancaster (1988) review of Quaternary environmental change in southern Africa as a whole is based on only marginally more evidence than the Deacon *et al.* (1983) review for the fynbos biome. Deacon and Lancaster (1988) incorporate the pollen work of Scholtz (1986) and are also able to draw on Klein's (1984) analysis of variation in large

mammal fossil size, as well as Deacon *et al.*'s (1984) multidisciplinary review of the evidence emanating from Boomplaas Cave. From these data, Deacon and Lancaster (1988) note that, although the earlier part of the Last Glacial Maximum may have been both cooler and wetter than present, '...the coldest and *driest* (author's italics) conditions of the last 125 000 years date (from) ...20 000 to about 16 000 BP' (p 146). Furthermore, Scholtz's (1986) pollen data for Boomplaas indicate that a greater proportion of precipitation, at the time of the Last Glacial, may have fallen during the summer than is currently the case in the southern Cape.

The Holocene is uniformly reflected as a period of temperature amelioration and the mid-Holocene is associated with temperatures warmer than at any time during the previous 125 000 years (Deacon and Lancaster, 1988), although there is less consensus around the quantity and seasonality of precipitation, which appears to have varied in a complex manner. Scholtz (1986) describes the Holocene vegetation at Boomplaas and also at the coastal forelands west of George. More xeric conditions seem to have prevailed during the earlier Holocene at Boomplaas, and the peat deposits at Norga, which date only to the last few thousand years, are consistent with the view that the second half of the Holocene was in general characterised by greater available moisture.

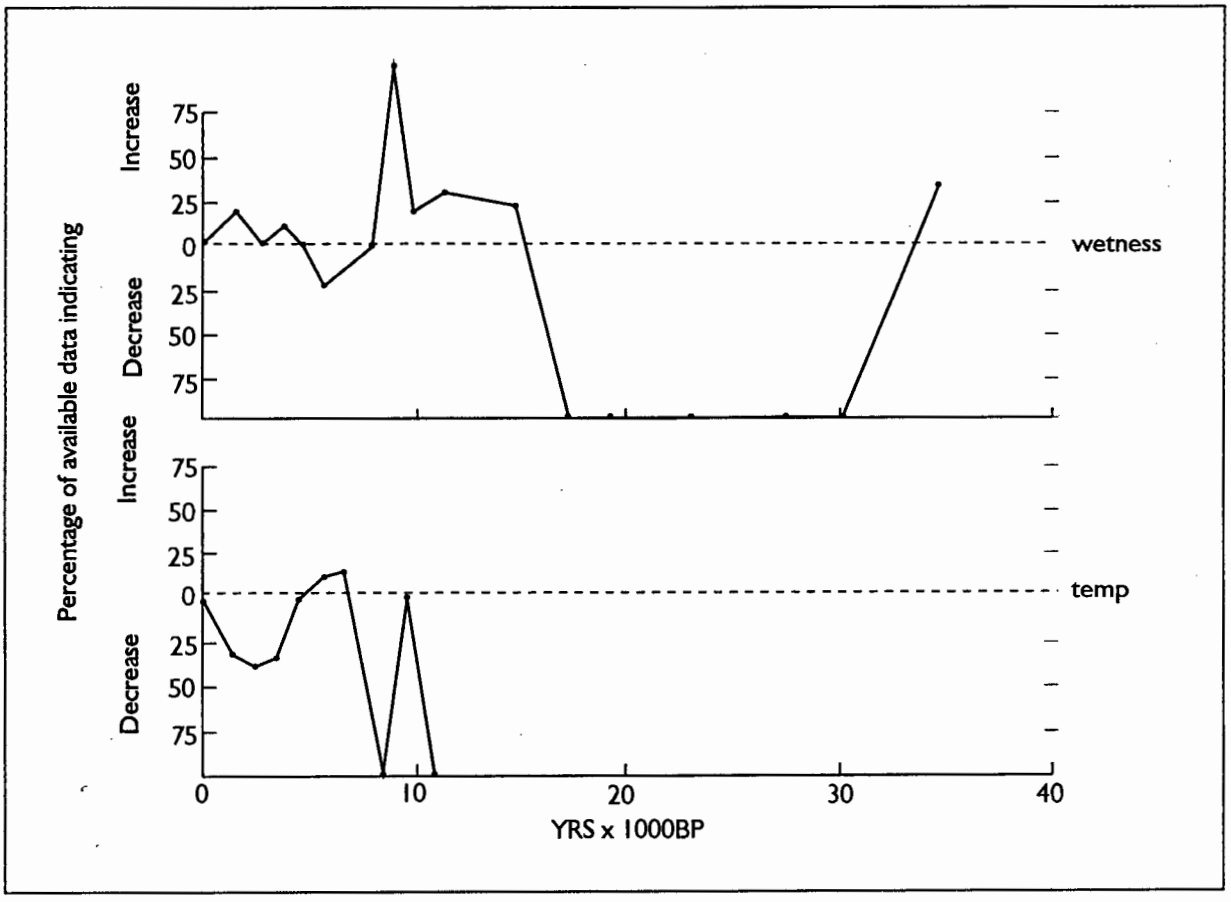


Figure 2.2 Partridge *et al.*'s (1990) reconstruction of the climatic conditions of the southeastern Cape.

Partridge *et al.* (1990). Following a workshop and the conference on southern African environmental change that took place under the auspices of the IGBP at the University of Cape Town in 1989, Partridge *et al.* (1990) have published the most comprehensive attempt thus far to synthesise the available Quaternary evidence with a view to establishing regional environmental change scenarios. Their view of environmental changes in 'region A', the southern and southwestern Cape, indicates a very dry and cool Last Glacial Maximum (refer to Figure 2.2), with temperatures from five to six degrees Celsius cooler than the present day. The synthesis suggests that the Holocene may have been subject to significant fluctuations in available moisture; while the immediate post-glacial period appears to have been markedly wetter, the remaining first half of the Holocene was considerably drier, coincident with the warmest temperature estimations. The second half of the Holocene seems to have been associated with greater moisture availability than the period 5 000 to 8 000 BP.

2.2.1.1 *Concordance and discordance in the literature*

The available palaeoenvironmental evidence indicates some problematic areas of disagreement regarding the nature of late Quaternary climates in the southwestern Cape (Table 2.1).

	Deacon *et al.* (1983)		Deacon & Lancaster (1988)		Partridge *et al.* (1990)	
	Temp	Ppt^{n}	Temp	Ppt^{n}	Temp	Ppt^{n}
5 000 to 0 BP	≈	≈	≈	↑	↓/↑	↑
10 000 to 5 000 BP	?	?	↑	↓	↓/↑	↑/↓
Last Glacial Maximum	↓	?	↓	↑/↓	↓	↓

Table 2.1 A comparison of late Quaternary palaeoenvironmental interpretations based on published regional syntheses for the southwestern Cape region. The symbols ↑, ↓, ≈, indicate *elevated*, *depressed* or *comparable* temperature and precipitation values respectively, relative to the present day situation. Where ↑/↓ or ↓/↑ occur, the interpretation suggests; higher followed by lower (and *vice versa*).

The temperature data present a consistent view that the Last Glacial Maximum was between five to nine degrees cooler than the present day and that these minima characterised the period from 21 000 to 17 000 BP. The so-called Holocene hypsithermal of the fynbos biome occurred during the mid-Holocene, probably around 7 000 to 5 000 BP and provided mean annual temperatures one or two degrees Celsius warmer than the present day. The precipitation situation, however, is subject to greater controversy,

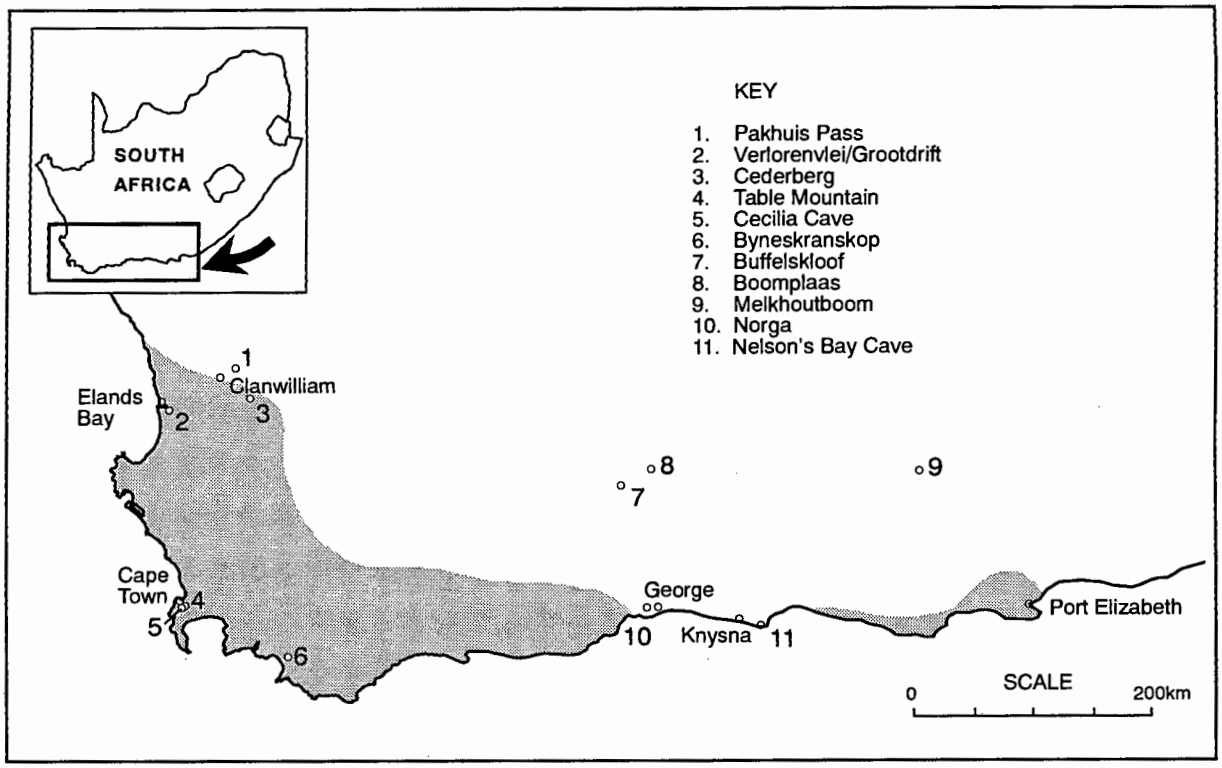


Figure 2.3 Location of sites mentioned in text and showing the southwestern Cape winter rainfall region.

perhaps in part because of the difficulty of reconstructing such a composite climate parameter on the basis of proxy evidence only. The earlier synthesis of Deacon *et al.* (1983) pointed mainly to a wetter Last Glacial Maximum, while the later reviews of Deacon and Lancaster (1988) and Partridge *et al.* (1990) offer the suggestion that this period was in fact rather more xeric in the region. There are a number of possible reasons for such an inconsistency, viz:

1. the data are too few and the proxy evidence insufficiently reliable to produce any coherent picture of regional precipitation change;

2. the earlier analyses were simply misinterpreted; more recent data points to a real decrease in available moisture at the time of the Last Glacial Maximum;

3. there is spatial differentiation across the region in respect of its response to late Quaternary precipitation changes (ie some areas were indeed drier, whereas others where wetter at this time);

4. the geographical distribution of studies of the late Quaternary in the southwestern Cape is uneven (Figure 2.3). With respect to palynological analyses in particular, the reconstructions have largely been restricted to wetland sites in the mountains (eg, Norga peat bog, Scholtz, 1986) or at the coast (eg, Wilderness Lakes, Martin, 1968). In each of these cases, however, the fossil sites fall within a part of the

fynbos biome that receives an all-year precipitation regime, and it becomes obvious that much of what has been reviewed thus far, including the large and micromammal evidence from within caves, does not fall geographically within the fynbos *sensu stricto* (Moll and Jarman, 1984). This opens up the possibility that the spatial differentiation in climatic response might have remained hidden due to the 'selection' of sites used in these syntheses.

In attempting to choose between which of these sources of discordance is most appropriate, it is worth considering some more recently published and previously unpublished palynological evidence concerning the nature of late Quaternary environments in the region.

2.2.1.2 *Recent evidence from the fynbos mountains*

The Cape Floristic Region's prolific plant species diversity is concentrated in the mountains of the southwestern Cape and it has therefore been a key goal in biogeography to attempt to reveal the role of Quaternary environmental change in the evolution of that diversity (Linder *et al.*, 1992). The uplands of the region are well endowed with wetland sites which have accumulated organic sediments potentially suitable for pollen analysis, but the deposits are frequently shallow in depth and do not extend very far back into the Holocene (Meadows, 1988b; Linder *et al.*, 1992). Nevertheless, it is now possible for the palaeoenvironmental implications of palynological analyses of sites from within the Cape mountains to be seen in the context of the region as a whole and in comparison with other forms of evidence.

The Cederberg. Pollen preserved in vlei sediments from the Cederberg mountains, at the northern end of the fynbos biome, have revealed a vegetation history spanning the last 14 500 years (Meadows and Sugden, 1990; 1991a,b). The record for the central and highest parts of these mountains is one of overall stability, despite the fact that the sediments straddle the terminal Pleistocene-Holocene boundary which has been shown to be a period of marked environmental dynamism in other parts of southern Africa (eg, Partridge *et al.*, 1990). The Last Glacial Maximum period is not visible from these vlei sediments, although Sugden and Meadows (1991) use the long-term decline in the abundance of the endemic Clanwilliam cedar, *Widdringtonia cedarbergensis*, to infer that Last Glacial conditions may have been more favourable to this tree species and, accordingly, were cooler and wetter than at present.

As an hypothesis, the interpretation that the Last Glacial in these mountains was cooler and wetter, remained untested until the work of Scott (1994) on hyrax midden deposits from the northeastern side of the Cederberg. Scott's analysis of pollen from hyracium at the Pakhuis Pass Shelter yields a picture of changing environmental conditions during the late Quaternary at the xeric end of the Dry Mountain Fynbos spectrum, since the area receives only around 450 mm precipitation (winter maximum) per annum in contrast to the vlei sites examined by Meadows and Sugden (1990, 1991a) which currently receive about twice that amount. Scott's (1994) pollen zone A, which is dated as older than 14 000 BP and encompasses the late Pleistocene and the Last Glacial Maximum, is dominated by pollen of Scrophulariaceae-type, *Stoebe*-type, *Cliffortia*, *Lobostemon*, Proteaceae and several ericoid elements. Scott's (1994) interpretation suggests a lowering of vegetation belts at this time and the shift, therefore, of vegetation types associated with higher altitude in the Cederberg to the lower slopes. Although not explicitly stated as such by Scott (1994), this implies cooler and possibly moister conditions at this time, since the contemporary climatic gradient is one of decrease in temperature and increase in precipitation in association with altitude in these mountains. Certainly the higher frequencies of Ericaceae pollen in zone A would support this suggestion, although Scott (1994) steers clear of assigning any moisture signals to most of the vegetation changes he describes. Cyperaceae and Restionaceae pollen do reach a peak between 16 000 and 15 000 BP and may indicate greater abundance of local wetland elements at that time.

The Holocene sequences are climatically in contrast to the earlier pollen levels at Pakhuis (Scott, 1994), suggesting that tree taxa became significantly more abundant in response to the climatic amelioration which followed the Last Glacial Maximum. Pollen of taxa such as Aizoaceae (mainly succulents, many of which are frost-sensitive) and asteraceous shrubs peak between 8 000 and 6 000 BP and point to the warmest periods of the Holocene as being times with lower moisture availability. In general, as elsewhere in the southwestern Cape, the first half of the Holocene is associated with more xeric conditions than the last 5 000 years. Woody elements in these hyracium deposits are generally more abundant in the Holocene and, in contrast to the long-term decline in *Widdringtonia* which points to the impact of pre-Colonial occupation on the Cederberg landscape (Sugden and Meadows, 1991; Meadows and Sugden, 1991a), show reductions in frequencies only in the most recent levels.

The Cederberg's rich supply of late Quaternary palaeoenvironmental information is suggestive, broadly speaking, of important environmental changes. The more upland sites may have been less sensitive to climatic fluctuations, but the lower altitude situation

as revealed by Scott (1994) points to a Last Glacial Maximum which was certainly cooler by several degrees, and quite possibly (if the environmental gradients of the present day trended in a similar direction in the past) associated with higher rainfall. Furthermore, periods of higher temperatures during the Holocene were marked by more xeric climates in these mountains.

Table Mountain, Cecilia Cave. Unpublished work by Baxter (1989) reports on an investigation of the polleniferous deposits from Cecilia Cave near Cape Town. Located at an altitude of approximately 550 m on the eastern flank of Table Mountain, the cave faces southeast and is therefore ideally situated as a pollen trap for material borne on the strongly prevalent summer winds. Sediments from the rear of the cave reveal a complex sequence of organic and other deposits and pollen has been derived from several levels within this sequence to facilitate the construction of a pollen diagram (Baxter, 1989). Despite the absence of marked pollen frequency changes, there are a number of features considered to be of palaeoenvironmental significance. The lowermost pollen spectrum, dated to around 8 000 BP, has the lowest values for pollen concentration coupled with highest frequencies of asteraceous pollen - a situation which prompts the conclusion that environmental conditions at the time were perhaps drier and, possibly, even warmer than currently prevail. This xeric phase is followed by a level in which the higher frequencies of both Ericaceae and Restionaceae are consistent with a scenario of greater moisture availability and, perhaps, slightly cooler temperatures. Baxter (1989) interpreted this to have occurred at approximately 3 000 BP, although, since the chronology is not well defined, it would be better to describe this simply as a late mid-Holocene permutation. The coincidence of (marginally) lower temperatures and greater moisture availability is worthy of note, especially in the context of the similar conclusions reached elsewhere in the fynbos biome in respect of the mid-Holocene (Meadows and Sugden, 1991a,b).

2.2.1.3 *New research objectives*

To date, much of the palynological evidence from the southwestern Cape has evolved from sites that are centred within the fynbos biome and are, therefore, ecologically 'secure' insofar as their modern vegetation compliment is concerned. Meadows and Sugden (1993), have speculated that low amplitude late Quaternary environmental changes within the fynbos strongholds may have induced a composite 'reshuffling' of fynbos communities as new environmental gradients became established. Such environmental fluctuations are believed to have stimulated allopatric speciation

and may help to explain the prolific diversity and plant species richness so characteristic of the fynbos vegetation today (Meadows and Sugden, 1993). This scenario implies that a certain degree of environmental resilience accompanied the fynbos during its late Quaternary evolution and prompts the question as to whether the palynological evidence from the core fynbos areas of the southwestern Cape may be concealing or moderating certain regional palaeoclimatic trends. While the answer to this conundrum remains elusive, it provides considerable incentive for the application of palynological studies in ecotonal areas of the fynbos biome where more sensitive vegetation alliances have come to be formed in response to critical thresholds imposed by changing climatic, edaphic and environmental conditions. Indeed, one of the primary objectives of this study is to conduct such an investigation in the northern Sandveld, an area which is recognised not only as an important ecotone between the fynbos and karroid floras but also as a region of considerable geoarchaeological and palaeoenvironmental significance.

2.2.2 Late Quaternary geoarchaeological evidence from the Sandveld

During the course of the last 25 years, several geoarchaeological investigations have been undertaken in the vicinity of Verlorenvlei, a fresh water coastal lake system located towards the northern extent of the West Coast Sandveld (refer to Chapter 3 for a comprehensive account of the contemporary geography). The evidence gained from these investigations intimates that Verlorenvlei, with its diverse natural resource base (encompassing marine, estuarine, fresh water and terrestrial components), was once an important geographical focus for the indigenous hunter-gatherer populations of the region (Parkington, 1981). Former prehistoric occupation sites in the Verlorenvlei area disclose a complex pattern of temporal and permanent settlement that lasted throughout the terminal Pleistocene and for much of the Holocene (ie the period spanning the last 30 - 40 000 years). Since 1969, John Parkington, has been investigating the archaeological data from two long-sequence cave sites, Elands Bay Cave (Parkington, 1976; 1981) and Diepkloof Cave (Parkington and Poggenpoel, 1987), both of which have sedimentary records dated to beyond the limits of conventional radiocarbon. While the major research objectives at Verlorenvlei have traditionally focused on the palaeoanthropology, there is mounting evidence to suggest that late Quaternary environmental fluctuations have had a profound effect in determining the subsistence economy and cultural expression of the former indigenous populations (Parkington, 1981; Parkington *et al.*, 1988). In turn, this realisation has prompted new research initiatives aimed specifically at elucidating the sequence of environmental

change at Verlorenvlei, in the hope that such an understanding will shed new light on the complex archaeological record of the region.

2.2.2.1 *The Last Glacial at Verlorenvlei*

Geoarchaeological evidence for the time of the Last Glacial Maximum is limited to a few observations surrounding the sediments from Elands Bay Cave and Diepkloof Cave. Butzer (1979), records a steady increase in transgressional sands between 20 000 and 11 000 BP in Elands Bay Cave, with complimentary data from surrounding slopes and from Diepkloof Cave. Miller (1987) confirms the presence of roof spalls among the Elands Bay Cave sediments and argues that 'frost shattering' and vigorous winds may have accounted for the observed sedimentary pattern. While it is undisputed that conditions were colder by about 6° C during the height of the Last Glacial, very little evidence concerning moisture availability is at hand. Butzer (1984b) suggests tentatively that active pedogenesis around Elands Bay may indicate increased surface stability and a reasonable measure of ground cover (this implies that conditions at the time were probably sub-humid) but this evidence does not accord with Klein's (1984) equally tenuous assertion that a reduction in the mean skeletal size of mole rats (*Bathyergus suillus*) indicates a decrease in vegetation density and therefore, reduced rainfall. Sea-levels, at the time of the Last Glacial Maximum, are projected to have been lowered by some 110 m and rivers such as those feeding Verlorenvlei, would have experienced substantial down cutting in an effort to realise their new base levels (Tankard and Rogers, 1978). Post glacial climatic amelioration and the subsequent eustatic rise in sea-level are believed to have introduced significant palaeogeographic changes to the Verlorenvlei region. Certainly, the coastal plains to the west of Elands Bay Cave would have been rapidly inundated, a process that would have eliminated 30 - 40 km of coastal plain in a matter of 6 000 years. Butzer (1979) has established that most aeolian deposits in the vicinity of Elands Bay are related to post-glacial marine transgressions, with the last major aeolian phase occurring around 12 500 BP. The sedimentary record from Elands Bay Cave confirms this trend, revealing a steady increase in the proportion of littoral-aeolian sands with a concomitant decline in the presence of roof spalls (Miller, 1987), a clear indication that temperatures had moderated and sea-levels were once again rising.

2.2.2.2 *Sea-level, climate and landscape changes during the Holocene*

By the end of the terminal Pleistocene, the sea had moved to within 5 km of the modern coastline and for the first time marine mammals, fish and birds are reflected in the archaeological record from Elands Bay Cave (Poggenpoel, 1987). The progressive drowning of the Verlorenvlei valley would have brought with it estuarine conditions and saline water proximal to Elands Bay Cave - an observation supported by the steady increase in marine artefacts (Parkington, 1986). Sea-level change is not the only environmental perturbation that characterised the transition to the Holocene. A dramatic change in the composition of large mammalian herbivores signals an important shift in local climatic and terrestrial environmental conditions between 11 000 and 9 000 BP. Large grazing fauna, such as the giant horse *Equus capensis* and the giant buffalo *Pelorovis antiquus,* appear to have given way to a new suite of small browsing ungulates including the grysbok *Raphicerus* (Klein, 1980), prompting the suggestion that more arid, possibly warmer conditions were encouraging the spread of succulent vegetation at the expense of grassland (Parkington, 1986). That conditions were more arid at this time finds a measure of support in the work of Cohen *et al.* (1992) who report on shell mineral and oxygen isotope changes in the shells of *Patella granatina.* These fossils, derived from occupation sites around Verlorenvlei, record a sea surface temperature anomaly between 11 000 and 10 000 BP which may indicate an intensification of upwelling events off the southwest coast. By about 8 000 BP the local archaeology reflects that subsistence economies at Elands Bay had shifted almost entirely from terrestrial to marine resources.

Occupation of cave sites within the lower Verlorenvlei valley ceased abruptly some time after 8 000 BP. Robey (1987) has speculated that increasing sea-levels during the early Holocene were responsible for inundating the rocky coastal platforms around Elands Bay and that access to critical food sources, such as mussels, was severely reduced. Sea-level fluctuations are believed to have reached their maximum extent some time around 4 000 BP (Miller *et al.*, 1993; Jerardino, 1993) when levels rose 2 - 3 m beyond those of the present day. It is hypothesised that lagoonal conditions would have developed at Verlorenvlei and the fresh water interface would have shifted inland by many kilometers, thus rendering the coastal shelters less desirable as permanent occupation sites. Palaeoenvironmental clues for this time period remain scarce and are generally limited to proxy evidence. Parkington (1984), citing the increased occurrence of halites and gypsum at Elands Bay Cave as evidence of intensified coastal fog, argues in favour of increased aridity during the mid-Holocene. This scenario presupposes a southerly deflection of cyclonic frontal systems, a decrease in rainfall and an increase in

coastal upwelling - a situation analogous to the modern coastal environments of the hyper-arid Namib. The initiation of deflation hollows among the Sandveld environments is entirely consistent with drier, possibly warmer conditions during the early to mid-Holocene (Lancaster, 1986).

Following supposed climatic amelioration around 3 000 BP and the isostatic equilibration of sea-levels to those approximately the same as today, archaeological evidence once again documents the presence of people at Verlorenvlei. Vast shellfish middens dated to around 2 800 BP indicate the reappearance of a rocky shoreline (Miller *et al.*, 1993) and renewed exploitation of the mussel *Choromytilus meriodionalis* (Buchanan *et al.*, 1983). By 1 600 BP nomadic pastoralists had arrived at Verlorenvlei (Klein and Cruz-Uribe, 1987; Sealy and Yates, 1994) and a new cultural, social and economic order had begun to make its presence felt among the Sandveld environments. The introduction of domesticated sheep and cattle into the region is expected to have induced changes in the vegetation ecology. In particular, pasturage, which would have included tracts of riparian vegetation, is considered to have been an important natural resource during seasonal occupations by herders (Smith, 1987). In this regard, observations by early European travelers suggest that deliberate burning of the reed beds was an established practice in keeping with a policy of grazing maintenance (Sinclair, 1980; Skead, 1980). Although it seems implicit that this manner of intervention is likely to have prompted at least some change in the structure and composition of the local vegetation, this hypothesis has yet to be adequately tested.

2.2.2.3 *The historical period (AD 1652 - 1996)*

The arrival of the first European explorers in the Verlorenvlei area circa AD 1655 has been well documented by Sinclair (1980). Historical records reveal that Verlorenvlei was colloquially named 'The Hippopotamus Valley of the Sand River' (Mossop, 1931) leading to the obvious speculation that *Hippopotamus amphibius* once occupied the valley. Curiously though, only passing reference is made to the presence of hippopotamus in Verlorenvlei (Waterhouse, 1932), possibly an indication that they had already been shot out by the time travelers began to frequent the Sandveld (eg, Valentyn, 1796; Skead, 1980). Continued hunting by settlers soon led to the extermination of the remaining large endemic mammals. Species such as elephant *Loxodonta africana*, rhinoceros *Diceros bicornis*, eland *Taurotragus oryx*, zebra *Equus zebra* and hartebeest *Alcelaphus buselaphus* were rapidly eliminated from a landscape in which they must have played a crucial role in maintaining the natural continuity and vegetation mosaic (Hendey, 1983).

Following the demise of the large indigenous fauna, informal cattle ranching became established and, by the middle of the 18th century, the sandy slopes adjoining Verlorenvlei were being cleared for the cultivation of wheat and other crops (Sinclair, 1980). Although elements of informal agro-pastoralism still persist at Verlorenvlei today, recent agricultural mechanisation, including mobile irrigation systems, have initiated the development of large-scale commercial potato plantations, fully dependent on water derived from the sensitive Verlorenvlei system.

2.3 Conclusion: an episodic and disjunct palaeohistory

Regional interpretations suggest that the summer-rainfall interior and the southern Cape may have been climatically out of phase with the winter-rainfall region of the southwestern Cape. Drier episodes in the southwestern Cape appear to be correlated with warmer temperatures while cooler conditions are generally associated with greater moisture availability (the opposite appears to hold true for the interior and the all-year rainfall region of the southern Cape). Evidence from the time of the Last Glacial Maximum in the southwestern Cape remains inadequate - especially in the absence of suitable organic deposits from this time period. The Holocene record for this region is somewhat better resolved, although the record remains enigmatic for the terminal Pleistocene and early Holocene (Deacon and Lancaster, 1988). Increasingly, it is becoming clear that regional generalisations, such as those afforded in the three major syntheses of Deacon *et al.* (1983), Deacon and Lancaster (1988) and Partridge *et al.* (1990), provide an inadequate basis for the reconstruction of late Quaternary climates and environmental responses. Instead it is proposed that greater emphasis be placed on multi-disciplinary studies within tighter geographical confines. The ecotonal region of the West Coast Sandveld and, specifically, Verlorenvlei, are considered to be unique environments in which to test multiple hypotheses regarding a wide range of different environmental parameters. In particular, the sedimentary record from the drowned Verlorenvlei palaeovalley is believed to hold vital clues with respect to sea-level fluctuations, fluvial-geomorphology, palynology, sedimentology and chronology (Miller, 1987) - all of which are expected to contribute significantly to: i) the reconstruction of southwestern Cape late Quaternary environments, ii) the interpretation of the complex Sandveld archaeological record and iii) the prediction of the response of the contemporary southwestern Cape climate and environments to the widely anticipated impacts of global warming.

Chapter 3

CONTEMPORARY SANDVELD ENVIRONMENTS

3.1 Introduction

The sections that follow in this chapter are designed to familiarise the reader with the general abiotic and biotic characteristics of the contemporary Sandveld region. More specifically, the intention is to convey a detailed biogeophysical account of the Verlorenvlei catchment, followed by a brief description of each of the study sites within the Verlorenvlei precinct. Owing to its status, both as a Ramsar site of international importance, and locally, as an aquatic ecosystem within a dryland environment, considerable scientific interest has, over the years, come to be focused on the ecology of Verlorenvlei. In 1986 a synopsis of all the existing information on the contemporary ecology of Verlorenvlei was published in a comprehensive report as part of the Council for Scientific and Industrial Research (CSIR) series on 'Estuaries of the Cape, Part II' (Sinclair *et al.*, 1986). This reference should be considered as a supplementary source of information for those readers wishing to investigate, in greater detail, aspects of the contemporary fauna, physico-chemical characteristics of the aquatic system, and the historical development of modern land ownership/uses. A comprehensive review of all these data would be counter-productive since the task has been cogently addressed by Sinclair *et al.* (1986) and an additional review is considered to be beyond the ambit of this study. A detailed biogeophysical description of the Verlorenvlei catchment is, however, a prerequisite for the individual site descriptions and subsequent palaeoenvironmental interpretation.

3.2 The Sandveld of the West Coast lowlands

The term 'sandveld' has a number of loose, yet commonly applied connotations when used to describe surficial geomorphology in different areas of southern Africa. In literal terms, the name implies a sandy area, usually occupied by natural vegetation (colloquially referred to as *veld*). There are many areas in the subcontinent, particularly along the coastal margin and the sandy desert regions, that qualify in terms of this description. Consequently, the term has come to be widely applied, as a casual descriptive definition, for almost any sandy-type environment in southern Africa. The 'Sandveld' of the West Coast region has a much more specific designation. Although it

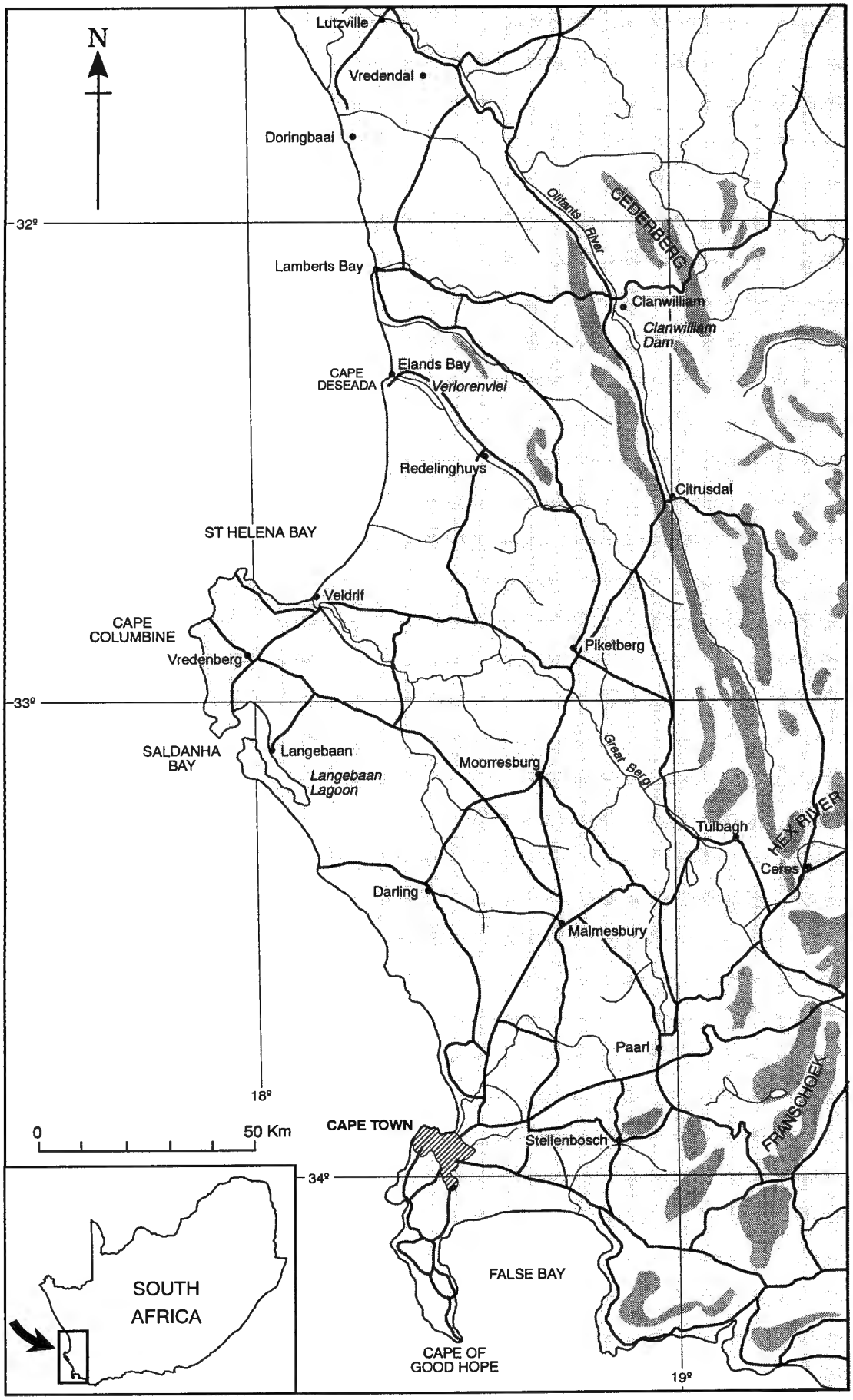


Figure 3.1 The West Coastal Lowlands in relation to the Cape Fold Mountains, Cape Province, South Africa.

supports the same basic geomorphological connotation as the term 'sandveld', described above, the 'Sandveld' is also the name given to a specific phytogeographical region along the West Coast of the Cape Province. This particular region is associated with a distinctive veld type, commonly referred to as *Strandveld*, or as Acocks (1988) would prefer it, Strandveld Proper. (Constituents and affinities of this predominantly open coastal sclerophyll scrub are discussed in more detail in subsequent sections). Given the potential for confusion regarding the terminologies of sandveld, Sandveld and Strandveld - aptly demonstrated in Harmse (1988) - it is worth pursuing clear and unambiguous definitions from the outset.

In his definitive study of gully erosion in the Swartland and Sandveld, Talbot (1947) draws the distinction, on the basis of relief features and regional climate differences, between a number of well-defined geographic regions in the Cape Province. Of these, the West Coast region is clearly delimited by the South Atlantic Ocean along the western boundary and by the northward extending Cape Fold Belt that rises up prominently in the east (Figure 3.1). An extension of the continental shelf (Lewis, 1974), the exposed low-lying coastal platform of the southwestern Cape, stretches from the Cape Peninsula in the south to the Olifantsrivier mountains, some 200 km to the north. The width of the coastal plain varies from about 40 km at its southerly margin (33° 50' S) to 120 km in the latitude of Saldanha Bay (33° S). For the most part, the lowland plains comprise a broad, undulating relief with the occasional granitic massif or sculptured quartzitic mountain, such as Piketberg (1 450 m amsl), persisting as monuments of former coastal islands or peninsulas that punctuated the shallow seas during the major Tertiary transgressions (Siesser and Dingle, 1981; Hendey, 1983; Rogers, 1987). Talbot further distinguishes the lowland plains, on the basis of geological substrate and derived vegetation types, into a higher-lying eastern component (the Swartland terrace) and a lower-lying western component (the Sandveld terrace). The Swartland, identified by relative elevation and topography, is believed by Talbot to have emerged from the shallow Tertiary (Eocene) seas somewhat earlier than the Sandveld lowlands to the west (Miocene and Pliocene). Although Tankard (1976) questions the lack of evidence in support of Talbot's hypothesis, the scenario does account logically for the present day differences in surface geology and veld types between the Swartland and Sandveld (Figure 3.2). In the event of the Swartland emerging first from the shallow sea, this region would have been subjected to a longer duration of sub-aerial denudation, river valley deepening and consequent surface erosion of the Tertiary deposits (Talbot, 1947; Hendey, 1983; Odendaal, 1983). By comparison, the lower elevation of the Sandveld would have reduced the potential for valley deepening and, coupled with a shorter duration of terrestrial erosion, denudation processes would have had insufficient time and less energy to remove the littoral and bottom deposits of the former Cenozoic seas - hence the distinctive sandy plains or

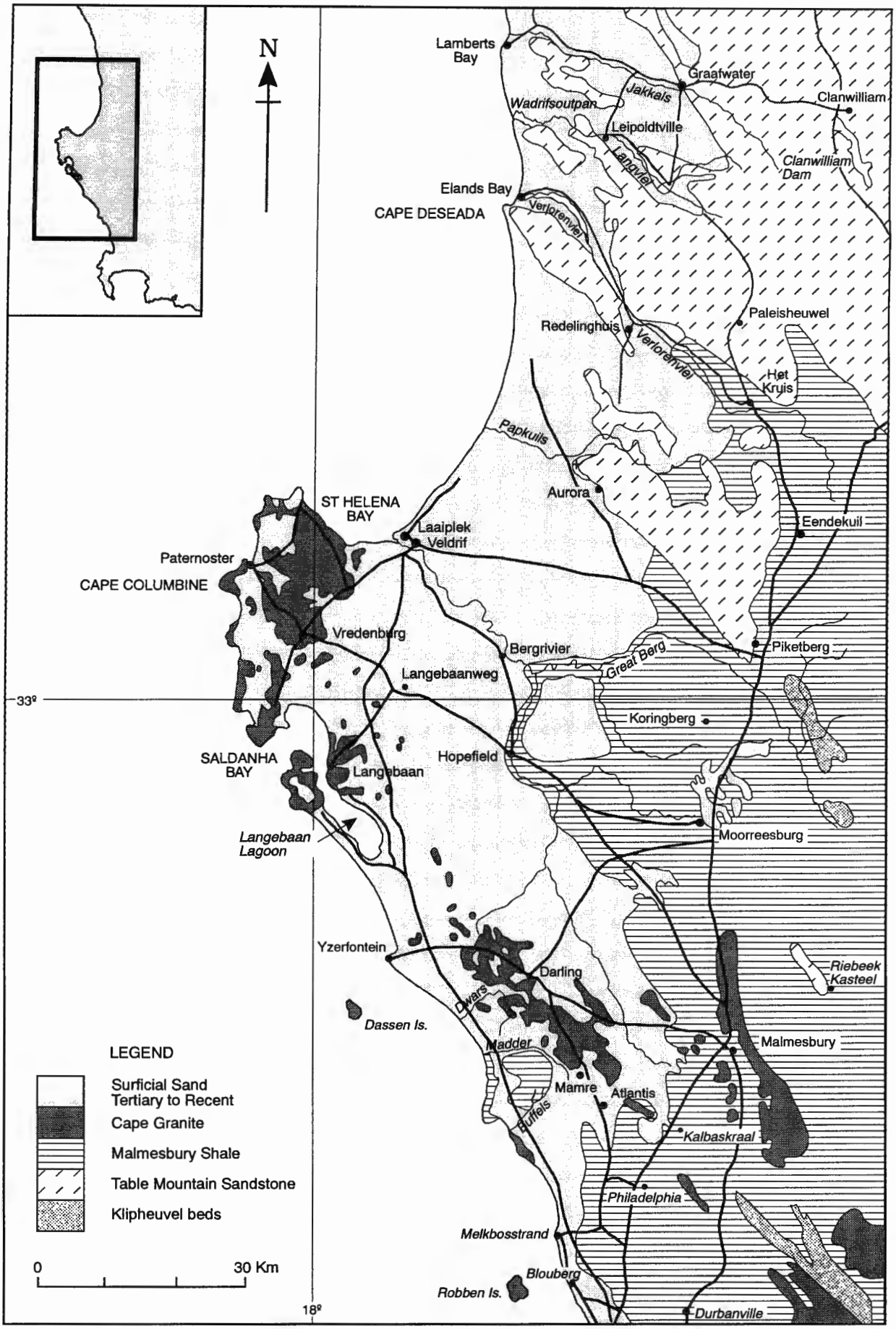


Figure 3.2 The Swartland and Sandveld regions defined on the basis of prevailing substrate. Adapted from Mason (1972).

'Sandveld' region (Visser and Toerien, 1971). If denudation processes have determined the geomorphology of the Swartland, then depositional processes have been the major influence in the formation of the contemporary Sandveld landscape (Harmse, 1987). Aeolian sands, derived ostensibly from former beach deposits (Tertiary to Recent) have blown inland and mantled much of the lowlands to form large areas with gently undulating surfaces, seldom exceeding a height of 60 m. Sporadic sandstone ridges, koppies (mesas and buttes) and insular granitic hills, protrude from the sand-sea to provide some interesting relief in the topographical monotony of the lowland coastal plain.

The physiography of the Sandveld coastline is dominated by the Vredenburg Peninsula, a substantial rocky promontory that forms the southern arc of St Helena Bay and the northern extension of Saldanha Bay (Figure 3.2). A sheltered marine embayment, divorced from the Atlantic Ocean by a resistant limb of Cape Granite, extends southwards from Saldanha Bay to form an impressive shallow-water (5 - 6 m deep) 'lagoon' at Langebaan (Flemming, 1977a). The product of Holocene sea-level rise and marine insurgence into a topographic depression (Rogers, 1987), Langebaan Lagoon (33° 06' S; 18° 01' E) adopts a bottle-shaped configuration with approximate dimensions of 16 km by 2 - 3 km. In the conventional sense, the marine water body is not a lagoon proper since there is no fluvial input into the system. However, certain lagoonal characteristics, evident in the ecology and hydrology, suggest that a prerequisite fresh water component may be derived via seepage (B Davies, personal communication) from the Elandsfontein and Langebaanweg aquifers (Tankard, 1974). To the south of Langebaan, log spiral sandy beaches extend towards the shores of Table Bay, while to the north, the extensive sandy shores of St Helena Bay curve 80 km to the prominent rocky point at Cape Deseada. Detailed descriptions of the lithostratigraphy and palaeoenvironments of this coastline and the immediate continental shelf have been made by Dingle (1973), Tankard (1976), Birch (1976), Tankard and Rogers (1978), and Rogers (1982; 1987).

Two significant, allogenic river systems bisect the coastal plain. Both the Great Berg River to the south and Olifants River to the north (Figure 3.1) have their origins in the Cape Fold Belt, to the east of the Swartland. The Great Berg is the largest river in the western Cape and, although it has a comparatively small catchment, some 4 012 km^2 is located within the highest winter rainfall region of the southwestern Cape, producing a mean annual run-off in the order of 234 x 10^6 m^3 (Day, 1981). From its source in the Drakenstein and Franschhoek mountains, the Berg River charts a course westwards, meandering along lines of weakness across the semi-arid Swartland and Sandveld floodplain, to emerge at Velddrif (32° 46' S; 18° 09' E) as an important estuary along the dry Atlantic

coast. The Olifants River, which drains the Kouebokkeveld mountains near Ceres, is constrained from traversing the coastal plain by the alignment of the Olifantsrivier and Cederberg mountains immediately to the west (Figure 3.1). The Olifants River is thus forced northwards for 100 km, receiving additional inputs from the Doring River and run-off from the semi-arid Cederberg extension of the northern Cape Fold Belt. A large dam has been constructed across the Olifants River valley at Clanwilliam and from this impoundment, water is harvested to service extensive irrigation projects. The remaining run-off drains northwards along the valley, finally emerging from the mountains at Vredendal. Here the river trends westwards in an arc across the southern Knersvlakte before meandering through the Sandveld to reach the coast north of Doringbaai (31° 42' S; 18° 11' E) some 130 km north of the Berg River estuary. Little is known of the hydrological dynamics of the Olifants River estuary and no report on the ecology of the system has been published. In addition to these two major drainage systems, a parallel series of minor structural faults trend northwest across the coastal plain, their origins apparently demarcated by the Swartland-Sandveld interface. Among these shallow valley faults, the Papkuils, Verlorenvlei, Jakkals and Langvlei Rivers offer ephemeral drainage to the semi-arid coastal plain (Figure 3.2).

3.2.1 Elands Bay and the wetland system of Verlorenvlei

Situated some 180 km north of Cape Town, at the northern extent of St Helena Bay and roughly midway between the estuaries of the Great Berg and Olifants Rivers, Elands Bay (32° 19' S; 18° 9' E) is a small marine embayment tucked behind a rocky groyne at Cape Deseada (Figure 3.3). The significance of Elands Bay as a coastal settlement, both in the modern and prehistoric contexts, is largely attributable to the proximity of an aquatic ecosystem that provides valuable fresh water resources in the otherwise marginal, semi-arid coastal landscape. This unique wetland system, comprising a river, swamp and semi-estuarine coastal lake, is collectively referred to as Verlorenvlei (pronounced, according to local dialect, as '*Fluor[e]-flay*'). Arguably the most important characteristic of this contemporary wetland habitat is the vital role it plays in supporting a diversity of aquatic avifauna, including over 60 species of waders (Sinclair *et al.*, 1986) and a number of birds which are listed as threatened '*Red Data*' species (Brooke, 1984). Indeed, because of the extreme aridity of much of the West Coast of southern Africa, Verlorenvlei, together with the Berg River floodplain, Langebaan Lagoon and Rocher Pan to the south, is a crucial environment for water birds, for it forms the last significant South African feeding ground on the migratory-bird flyway to Europe and northern Asia (Hockey, 1993) - the next links in the Atlantic coastal flyway are Walvis Bay, some

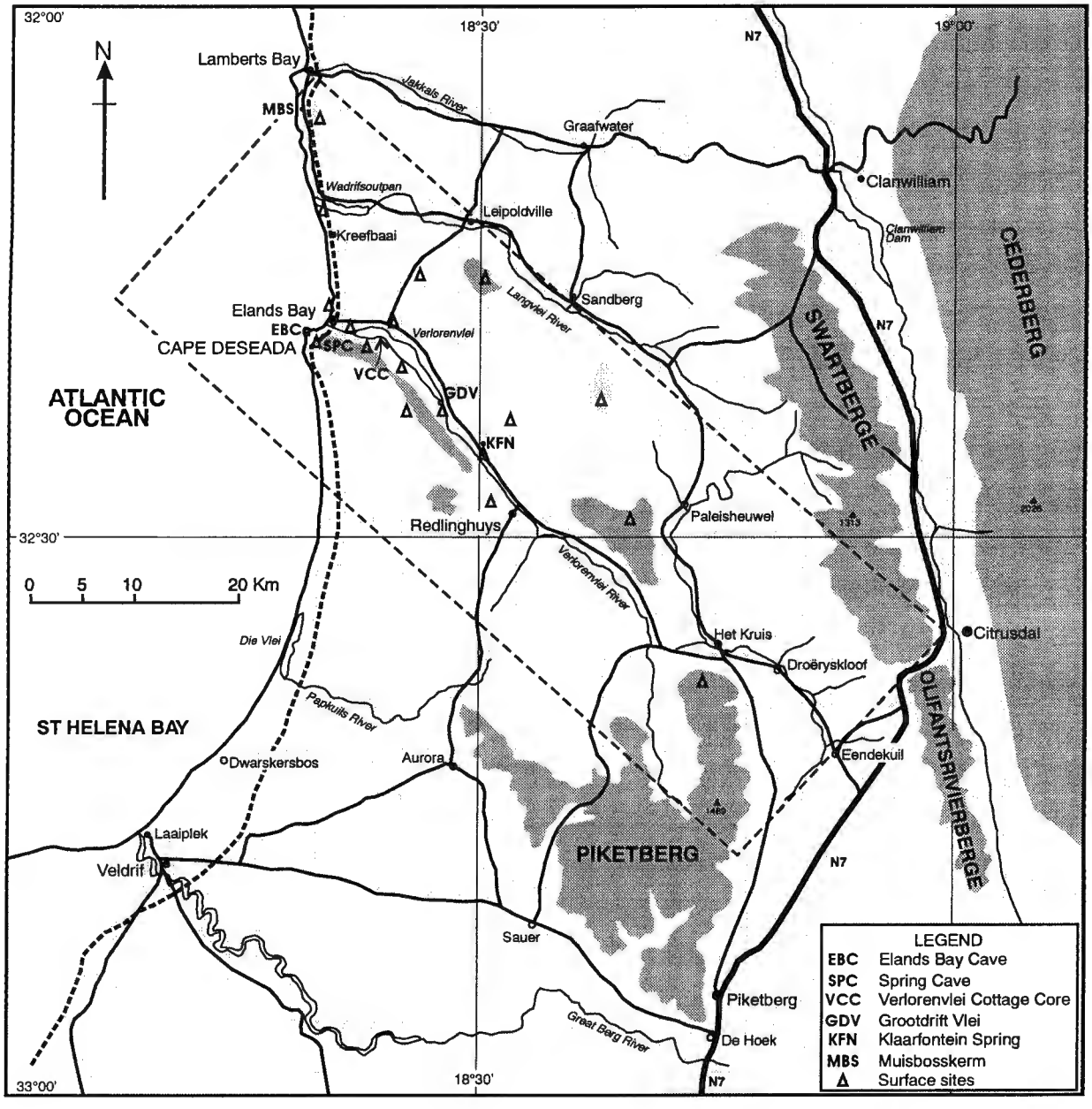


Figure 3.3 The northern Sandveld, Verlorenvlei and the primary study sites. The rectangle illustrates the east-west transect from which the surface pollen samples were collected : refer to Table 6.4.

2 000 km to the north in Namibia, and the Cunene River estuary in Angola (Simmons *et al.*, 1993), with the full extent of the Namib Desert lying between the latter and the wetland of Verlorenvlei.

The most striking feature at Verlorenvlei is the presence of a 10 km^2 body of permanent open water (known locally as a vlei). Measuring 13.5 km in length by 1.4 km at its widest point, the vlei is maintained in a silted basin, some 3 km from the sea. As with the evolution of Langebaan Lagoon, the development of Verlorenvlei is also attributed to a post-glacial rise in sea-level, which, in this case, back-flooded the former river valley to produce an active estuary during the mid-Holocene (Rogers, 1987). In support of this

interpretation, off-shore bathymetry reveals the westward extension of the palaeovalley as a submarine feature across the inner shelf (J Parkington, personal communication). Bathymetric studies conducted in Verlorenvlei by Grindley *et al.* (1982), reveal a shallow lake, achieving a maximum centrally-located depth of 5 m with evidence of active siltation from both proximal and distal ends. The infrequent and highly variable nature of the contemporary fluvial-marine exchange mechanism has resulted in a number of attempted formal classifications for the vlei. These include; coastal lake (Noble and Hemens, 1978), blind estuary or estuarine lagoon (Reddering, 1980), and estuarine lake (Miller, 1987).

The complete topography and watershed delineation of the catchment (Figure 3.4) is clearly defined on the map series; SOUTH AFRICA 1 : 500 000, sheet 3117 Calvinia, first edition (1980). For improved resolution, the map series SOUTH AFRICA 1 : 50 000, sheets 3218AD Elandsbaai and 3218BC Redelinghuys, second edition (1986), provide more detailed coverage. The topography ranges from sea-level at Elands Bay to a maximum watershed height of 1 489 m amsl on Sebrakop in the Piketberg mountains, some 87 km from the coast. By comparison to the Olifants and Berg River systems, the Verlorenvlei catchment is modest, draining an area of approximately 1 890 km^2 (Noble and Hemens, 1978). Furthermore, the catchment is well defined in terms of the geographic limits as distinguished for the Swartland-Sandveld region. Verlorenvlei is fed by an intermittent and highly seasonal river and spring system, with the majority of its input coming from the headwaters of the Kruismans River tributary that drains the northern Piketberg extension and Olifantsrivier mountains. Secondary inputs are received from the Bergvallei River tributary that drains the Swartberg and Maanberg ranges, and the Krom Antonies and Hol River tributaries that drain the southern extent of the Piketberg mountains. In addition to the fluvial contribution, a number of small artesian-type springs, dikes and sandstone seeps feed directly into the Verlorenvlei River from blind valleys among the Sandveld koppies. Unlike the Berg and Olifants Rivers, the Verlorenvlei River receives no input from the generous catchments of the Cape Fold Belt mountains in the eastern interior. As such, active flow is restricted to the months between June and November, accounted for by winter rains. Tributaries such as the Hol and Krom Antonies flow only occasionally, following good rains. No formal gauging stations exist within the catchment, and estimates of run-off are difficult to make under the present scenario of massive water abstraction for dryland irrigation. Unconfirmed appraisals by the South African Department of Water Affairs suggest that less than 20 % of the potential surface run-off from the catchment eventually reaches the lower wetlands of Verlorenvlei - a figure consistent with similar systems in the southwestern Cape (B Davies, personal communication)

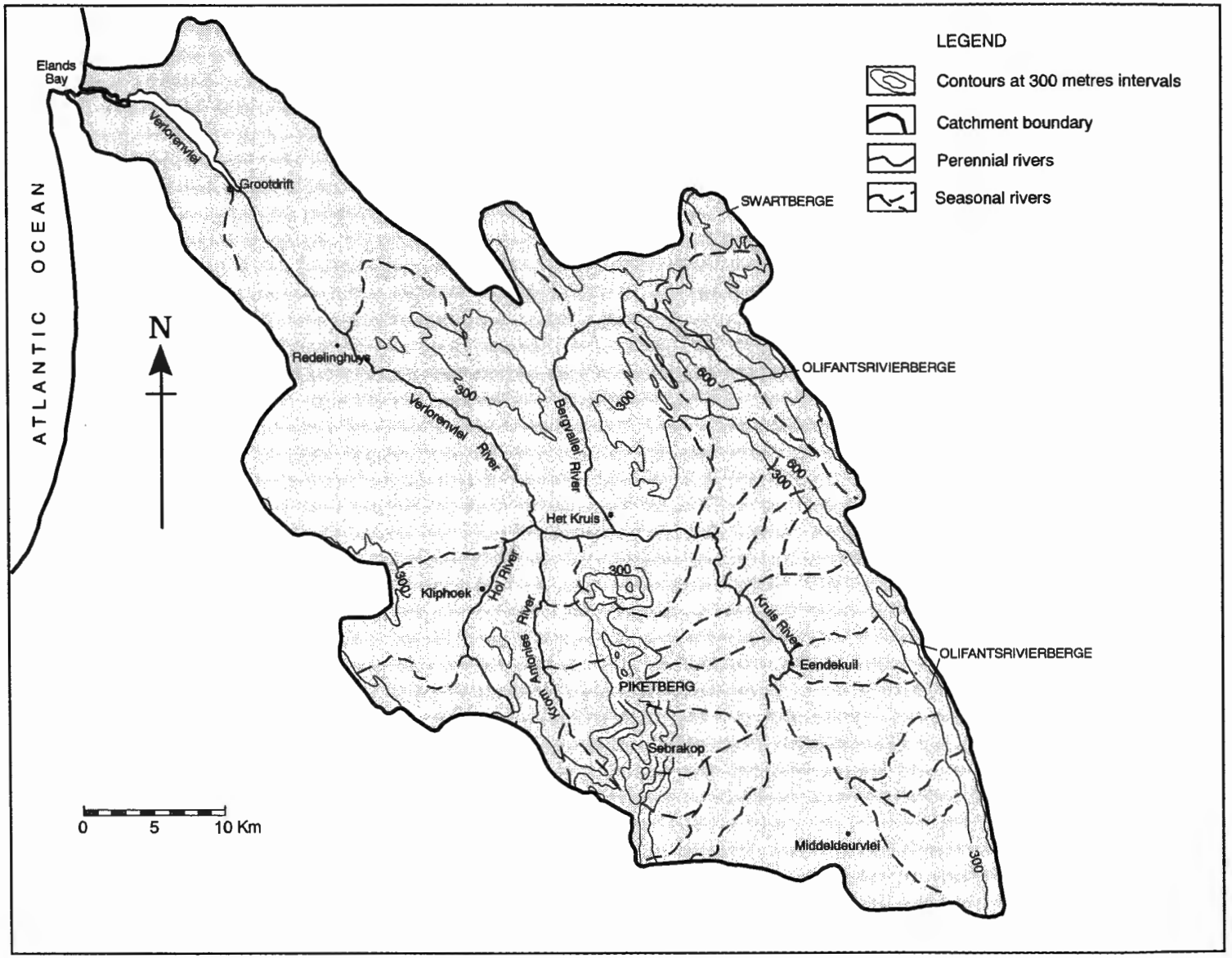


Figure 3.4 Verlorenvlei catchment showing topography and drainage. Adapted from Robertson (1980).

The valley along which the Verlorenvlei River negotiates its passage through the extensive, undulating sandy plains, follows a northwest/southeast structural trend for some 40 km towards the coast (Grindley, *et al.*, 1982). The presence of this strike fault is further accentuated by a significant parallel 'Krantzline', or continuous sandstone ridge. Averaging 120 m amsl, the ridge lines the southwest bank of Verlorenvlei for approximately 25 km between the inland settlement of Redelinghuys and the rocky coastal outcrop at Cape Deseada. On reaching the broad swampy plains near Redelinghuys, the meandering course of the Verlorenvlei River is funneled into a narrow, deeply incised valley that extends for 10 km, before emerging into a less constrictive valley at Grootdrift. Here, the river disappears among the expansive *Typha* and *Phragmites* reed beds that mark the transition to the extensive open water vlei. Along the southwestern shoreline of the vlei, steep rocky slopes extend down to the riparian fringe from Muishoekberg (309 m amsl) and Uitkykberg (209 m amsl). This abrupt topography has resulted in the development of a few small alluvial fans at the mouths of minor streams on Muishoekberg (Miller, 1987). Along the opposite, northeastern shoreline a more subtle gradient is encountered. Here, exposed sandy beaches are a feature of the modern shoreline which rises gradually to 10 m amsl. At this elevation, a punctuated rise of slope is attributed by Visser and Toerien (1971) to be the product of a former erosion level. The permanent open water extends from the inland reed beds at Diepkloof, past Uitkykberg, and into the Verlorenvlei Farm embayment, some 5 km from the coast. At Verlorenvlei Farm, as with the proximal end of the lake at Diepkloof, reed beds dominate in the variable shallow waters. From this point, sinuous channels of open water converge towards the coast to form a single narrow (± 50 m) channel at Bobbejaanskop. From here, the channel trends south and parallel to the coastline for 2.5 km before crossing a rock bar (1 m amsl) and terminating at a sand barrier on the beach southwest of Elands Bay village (Figure 3.5).

As is common with many South African rivers, Verlorenvlei is not an estuary in the classical sense, as access to the sea is restricted by the presence of a sand bar across the mouth. For most of the year the estuary channel is hydraulically-inactive, although good winter rains occasionally provide sufficient impetus to flood the channel. Owing to the shallow nature of the Verlorenvlei system there is seldom sufficient erosional power to breach the natural sand bar obstruction on a regular basis - a functional limitation that has been compounded through the presence of an illegal causeway. When fluvial exchange with the sea does take place, it is more often a result of a gradual damming effect imposed by the sand bar which then collapses under the progressive hydraulic load. These uni-directional fluvial pulses are usually limited to a few weeks during the winter months, following adequate seasonal rains. Marine inputs are generally rare and

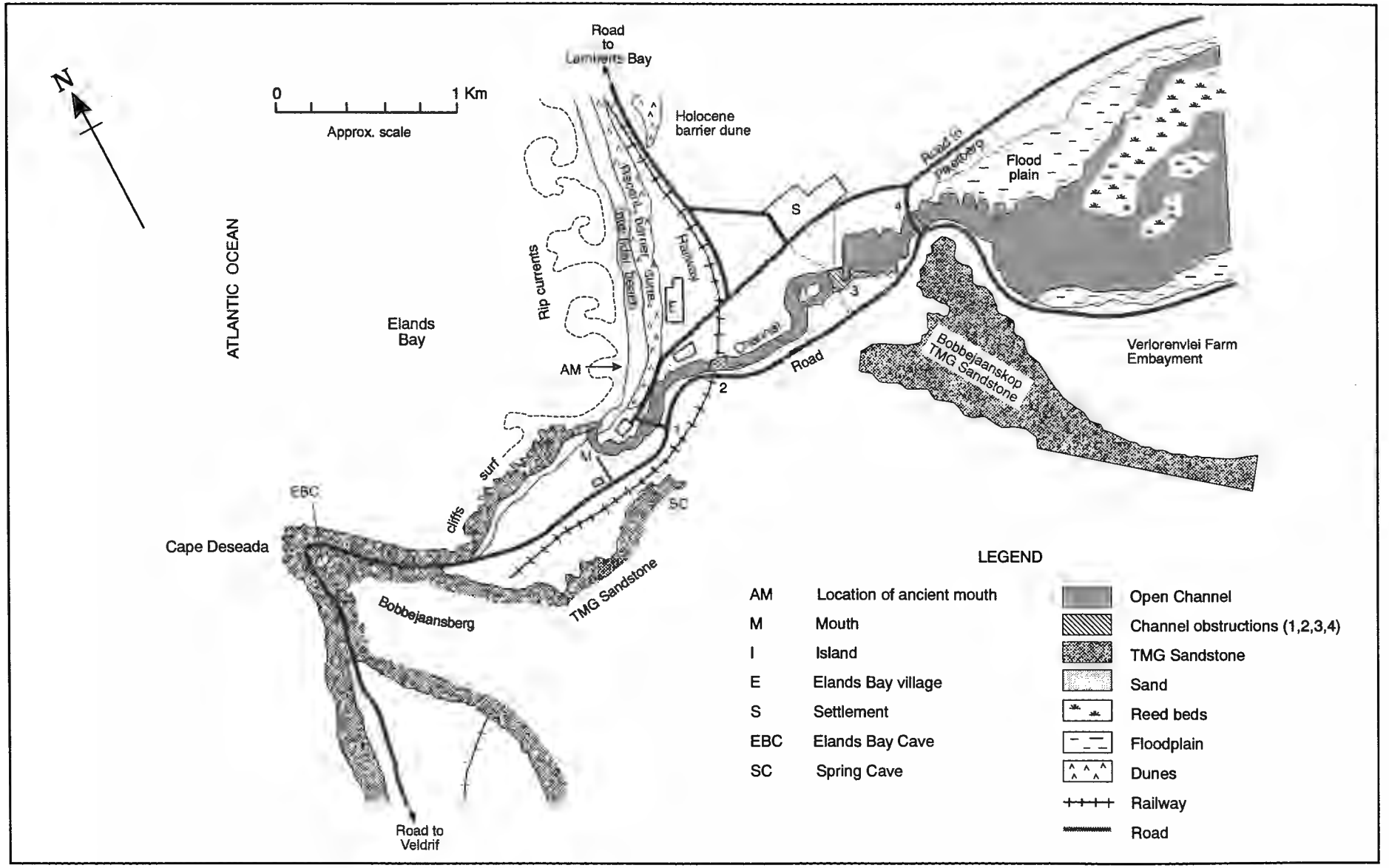


Figure 3.5 Elands Bay and Verlorenvlei estuary channel. Adapted from Sinclair *et al.* (1986).

are attributable to storm events that induce spillage over the beach barrier. In the absence of an impounded fresh water component, the sea water simply collects as hypersaline pools in the channel immediately behind the sand bar obstruction. On rare occasions, coinciding with equinoctial spring tides, sea water has been known to intrude the channel, occasionally penetrating the lower reaches of the Verlorenvlei Farm embayment - as was the case in June 1979 (Robertson, 1980). There is no historical record of any dual, two-way flow as would be expected from a more substantial permanent estuary system such as the Berg River estuary. Given the variability and the nature of the fluvial-marine interaction, it is clear that no simple classification will suffice in terms of a formal description for Verlorenvlei, although the most embracing description is probably that of 'intermittent estuarine lake'. Regardless of semantics, it is important to recognise that this variable and intermittent hydrological regime has allowed for the development of a unique and fragile aquatic ecology at Verlorenvlei (Sinclair *et al.*, 1986). Equally significant is the realisation, based on accruing geomorphological and sedimentological observations, that the system has, in the past, experienced far more dynamic interactions with the sea than the relationship exhibited at present. Miller *et al.* (1993) and Jerardino (1993) report on presumed alterations in the estuarine status of Verlorenvlei in response to mid-Holocene sea-level fluctuations. When viewed against the modern coastal geomorphology near the present mouth, it is readily apparent that any minor rise (1 - 2 m) in relative sea-level will see a permanent reversion to fully estuarine or even marine lagoonal conditions at Verlorenvlei.

In recent years the modern channel has become impeded (but not entirely obstructed) by two causeway crossings and, to a lesser extent, a railway bridge (Figure 3.5). The main causeway negotiates the channel, via culverts, immediately opposite Skietkop and carries the major secondary road that connects the southern farms to Elands Bay village. The second causeway has been established on a rocky sill approximately 500 m upstream of the mouth. The location, erection and authenticity of this causeway are of far greater concern. Since its informal and illegal construction by farmers during the 1970's, the causeway has been a source of continual dissent between local farmers and fishermen wishing to expedite their journey to Elands Bay village (reducing the distance by 4.5 km) and by conservationists wishing to see the natural hydraulic regulation of the channel proceed without the unnatural impedance caused by the causeway. The dispute regarding the legitimacy of the causeway has dragged on more than 25 years. Finally, through the efforts of various interest groups (Verlorenvlei Omgewingstaakgroep, 1993), coupled with the submission of a published historical-ecological case study of the system (refer to Baxter and Davies, 1994), the matter was brought to the attention of local Members of Parliament. At a fiery public meeting, held

at Elands Bay village in July 1995, representatives of the Provincial Government announced that the offending causeway was to be removed in its entirety (South African Department of Environmental Affairs and Tourism, 1995).

3.2.2 Geomorphology, geology and soils

The origin and geomorphological development of the Sandveld coastal plain has been studied in detail by Odendaal (1983) and Hendey (1983), while Harmse (1987) has investigated the geomorphological history and present deformation of the subaerial deposits. A comprehensive account of the regional geology of the Sandveld is offered in Visser and Toerien (1971), while Talbot (1947) and Schloms *et al.* (1983) offer detailed edaphic accounts of the soils of the Sandveld and Cape coastal platform respectively. For the most part, discussion concerning the geomorphology, geology and soils herein centres around the Verlorenvlei catchment (Geological sheet 3118C / 3218A), since the abiotic characteristics of the catchment are known to have a profound influence over the nature and composition of the biotic component, especially vegetation. The surface geology of the Verlorenvlei catchment (Figure 3.6) is composed of fine-grained rocks and metasediments of the Malmesbury Group; quartzitic sandstones and conglomerates of the Table Mountain Group; micaceous shales of the Klipheuwel Formation and abundant Tertiary to Recent sands of variable origin.

According to Rogers (1987), there is a direct correlation between the morphology of the pre-Cenozoic bedrock surface and the geology and topography of the modern coastal plain. The oldest rocks are metasediments belonging to the Precambrian Malmesbury Group and they have been divided on lithological grounds (Visser and Toerien, 1971) into three sub-groups, namely: calcareous (limestone and dolomite), quartzose (quartzite, schist and conglomerate), and phyllite (greywacke and blue-black phyllite). Deeply weathered Malmesbury metasediments underlie St Helena Bay and provide the structural foundation for the surficial sands that dominate the adjacent coastal plain (Theron, 1983). Along the slightly elevated eastern (Swartland) component of the coastal plain, Malmesbury shales are well manifested as weathered outcrops in the rolling topography. Here, the shales are expressed among the surficial soils as shallow gravelly loams, overlying subsoil accumulations of ferruginous concretions and impervious sandy clays. With the introduction of the plough, the decomposing shales, subsoil clay and ferruginous material have been mixed with the surface material to produce a 'concretionary sandy clay loam' (Talbot, 1947). Despite poor phosphate and nitrogen content, these soils have come to be recognised for their potential as grain

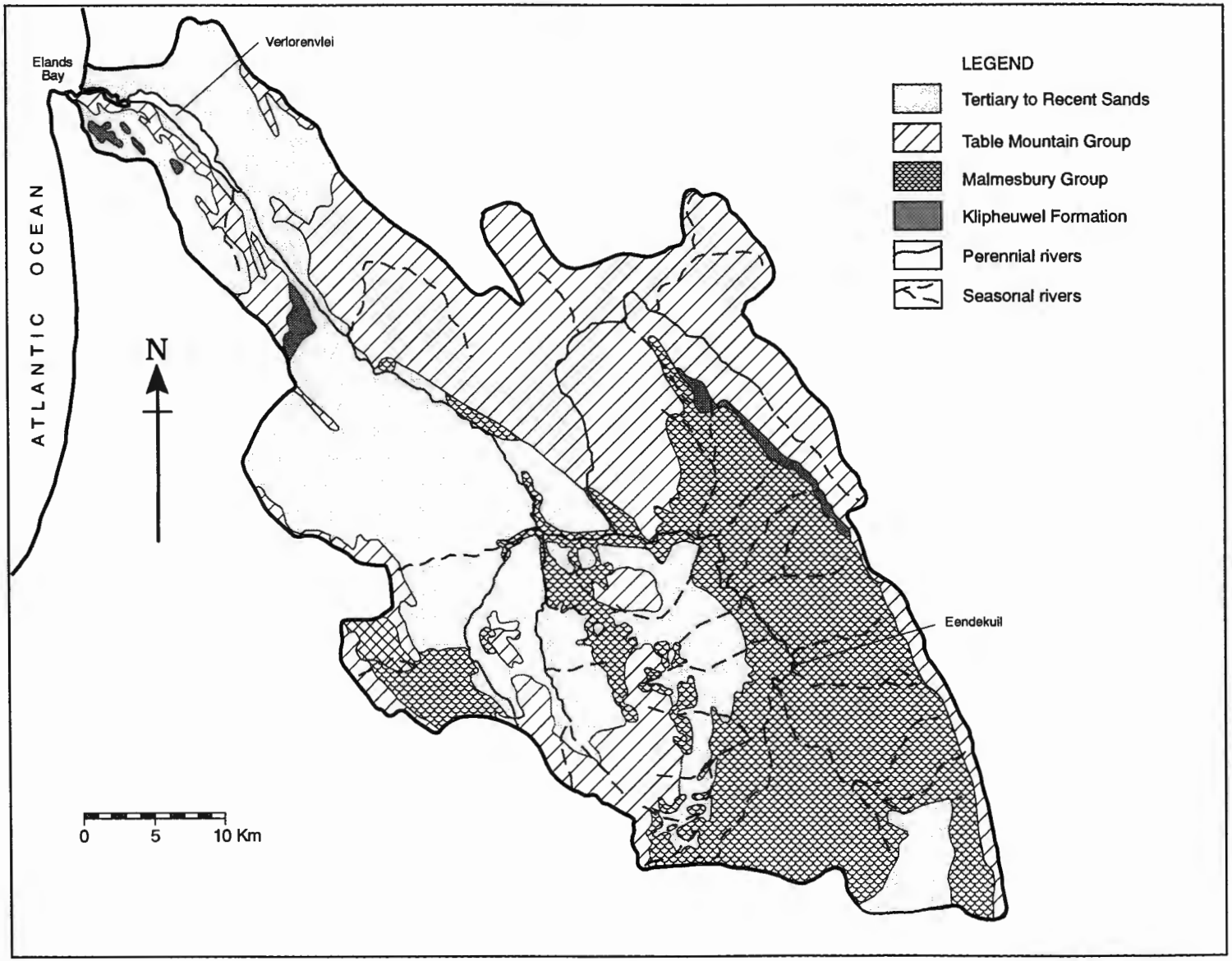


Figure 3.6 The geology of the Verlorenvlei catchment. Adapted from Robertson (1980).

producers and today the Swartland is extensively cultivated for winter wheat. About 30 % of the total surface geology of the Verlorenvlei catchment is comprised of the Malmesbury Group, although this formation is confined to the eastern Eendekuil region, towards the upper reaches of the Kruismans River. Grindley and Grindley (1987) have estimated that more than 90 % of the Eendekuil basin has been ploughed for agriculture and that enhanced salt leaching has resulted in elevated levels of sodium and chloride ions reaching Verlorenvlei.

Throughout the coastal plain, sandstones of the Table Mountain Group (Upper Silurian - Lower Devonian) punctuate the regional physiography as minor escarpments (such as Piketberg, 1 450 m amsl) or as individual outliers and ridges, separated by the pattern of northwest-trending strike faults (Rogers, 1987). The major constituent of this group is medium to coarse-grained, white to reddish brown sandstone. Cross-bedded fine-grained shaley sandstone and conglomerate with quartzite-type pebbles are also plentiful among the basal strata of the sequence. The conglomerates are of fluvial origin and constitute the Piekenierskloof Formation, above which the shaley sandstones, referred to as the Graafwater Formation, are suggestive of an estuarine or lagoonal origin (Visser and Toerien, 1971; Theron, 1983). The most prominent Table Mountain Group features in the Verlorenvlei catchment are the Piketberg escarpment and the extensive sandstone ridge between Redelinghuys and Cape Deseada. Between Elands Bay and Lamberts Bay, north and east of Het Kruis and Redelinghuys, small koppies and mountains of the Piekenierskloof Formation lie scattered across the landscape. The Table Mountain Group contributes some 30 % to the surface geology of the Verlorenvlei catchment but since most of these resistant sandstone features are elevated, they account for a considerable proportion of the actual drainage.

Rogers (1904, in Sinclair *et al.*, 1986) first reported the occurrence of poorly-bedded micaceous shales, sandwiched between the Malmesbury and Table Mountain Groups. Given the high degree of lithological similarity between these sediments and those in the Nama System, they have come to be distinguished from the Table Mountain Group as the Klipheuwel Formation (Proterozoic). Mostly poorly bedded, the Klipheuwel shales grade into mudstone and sandy shale with colours ranging from buff to a characteristic purple hue. These Klipheuwel sediments do not contribute significantly to the present surface geology of the Verlorenvlei catchment. However, given their exposure, due to erosion along the base of sandstone mountains (for example, the northwest margin of the Olifantsrivier Mountains, the base of Klein Tafelberg near Redelinghuys, and at the foot of Bobbejaansberg near the southwest shore of Verlorenvlei), it is possible that the

Table Mountain Group sandstones overlie more extensive occurrences of the Klipheuwel formation.

Implicit within its name, the Sandveld is dominated by a thick mantle of surficial sands. These poorly stratified Neogene deposits have originated in response to multiple sea-level fluctuations during the late Tertiary and Quaternary. A sequence of marine terraces has been identified from along the coast and these correspond to 120 m, 45 m, 27 m, 18 m, 6 m and 3 m amsl (Visser and Toerien, 1971). In addition to the predominant marine and aeolian inputs, these extensive sand deposits have also received contributions from the Table Mountain Group, particularly in the form of fluviatile sediments of past and present drainage systems (Sinclair *et al.*, 1986). A tentative stratigraphical nomenclature has been proposed by Rogers (1982) to describe the Cenozoic sediments at Elands Bay. Briefly, they comprise a three-tier stratigraphy with the peaty clay and sand of the Elandsfontyn Formation beneath, the conglomeratic phosphorite of the Varswater Formation in the middle, and three aeolianite phases (the uppermost being unconsolidated) of the Bredasdorp Formation on top. The depth of the aeolianite deposits at Verlorenvlei vary from 9 - 67 m and they contribute to some 40 % of the surficial geology of the catchment. The arenosols derived from these marine, aeolian and alluvial sands are fine-grained and loose, and exhibit poor water retention capacity and a low reserve of weatherable minerals (Schloms *et al.*, 1983). Generally, the littoral soils at Verlorenvlei are too dry for sustainable cultivation. Furthermore, they are frequently nutrient poor, acidic (inland) and highly leached (Talbot, 1947). Towards the coastal zone the soils become alkaline, with the proportion of nitrogen, potash and phosphates increasing relative to other western Cape soils. In addition, lime accumulations, gypsum and ferricrete deposits are not infrequent. An important geomorphological feature along the coast, immediately north of the Verlorenvlei mouth and the settlement of Elands Bay, is the presence of an extensive coastal dune system. Miller (1987) ascribes the formation of these active dunes, up to an elevation of 90 m, to aeolian reworking of marine sediments following the mid-Holocene transgression (Yates *et al.*, 1986). A characteristic feature of these recent deposits is the high content of finely-fragmented bleached calcium carbonate (shell) that contributes to a stark white appearance of the overburden (personal observation).

Although it makes no contribution to the surface geology of the Verlorenvlei catchment, it is worth mentioning the role of the Cape Granite Suite in determining the distinctive geomorphology of the Vredenburg Peninsula. Rogers (1987) describes the Vredenburg Peninsula as a structural expression of the Cape Granite Suite that extends from the Cape Peninsula in the south as a series of Cambrian plutons. The granites are

deeply weathered and form characteristic symmetrically convex hills with exposed granite boulders. Derived soils are generally poor in nitrogen and phosphates, and range from reddish sandy loams to highly consolidated ferruginous gravel (Talbot, 1947).

The Sandveld is also renowned for the presence of a curious geomorphological phenomenon known as 'heuweltjies'. These peculiar mima-like earth mounds are easily detectable, both on the ground and on aerial photographs, and occur throughout the Sandveld, including the Verlorenvlei region. The regular symmetry and appearance of the heuweltjies (approximately 20 - 30 m in diameter, rising gently by a meter or so to a central mound) together with their distinctive calcareous composition, have proved to be something of an enigma to soil scientists (van der Merwe, 1940). Numerous theories have been proposed to account for the origin(s) of these heuweltjies (Knight, *et al.*, 1989), including the interpretation by Burgers (1975) that they evolved during a different climatic regime around 12 000 BP, when grasslands, characteristic of the African savanna, are thought to have encouraged the activity of termites such as *Macrotermes* spp. Initial investigations by Lovegrove and Siegfried (1986) and more recently by Moore and Picker (1991) confirm the theory that heuweltjies are the residual by-product of ancient (and in some cases active) subterranean termitaria. The central calcareous hive, which may extend for some 2 m into the soil, has developed in response to large quantities of organic matter being introduced into the nest by the harvester termite *Microhodotermes viator*. Over time the organogenic termitaria have become fossilised, resulting in chemical and textural aberations in the soil profile.

3.2.3 Contemporary climate

The Sandveld falls within the winter rainfall area of the southwestern Cape and satisfies the criteria for a Mediterranean-type classification. Rainfall, which varies from 450 mm year^{-1} near Melkbos in the south, to less than 100 mm year^{-1} in the Knersvlakte to the north (Sinclair *et al.*, 1986), is highly variable and strongly seasonal, with the region receiving almost 80 % of its annual precipitation during the months from April to September. Rainfall is generated largely by cyclonic frontal systems which originate from disturbances between air masses in the South Atlantic (Preston-Whyte and Tyson, 1988). Occasionally, during spring and autumn, cut-off low pressure cells may act to supplement the predominantly frontal rainfall. During winter, the amplitude of the westerly disturbances is greatest and the south Atlantic Anticyclone migrates northwards such that cold fronts, under the influence of cyclonic westerlies, routinely clip the southwestern Cape (Tyson, 1986). Despite the seasonal oscillation in the latitude of the

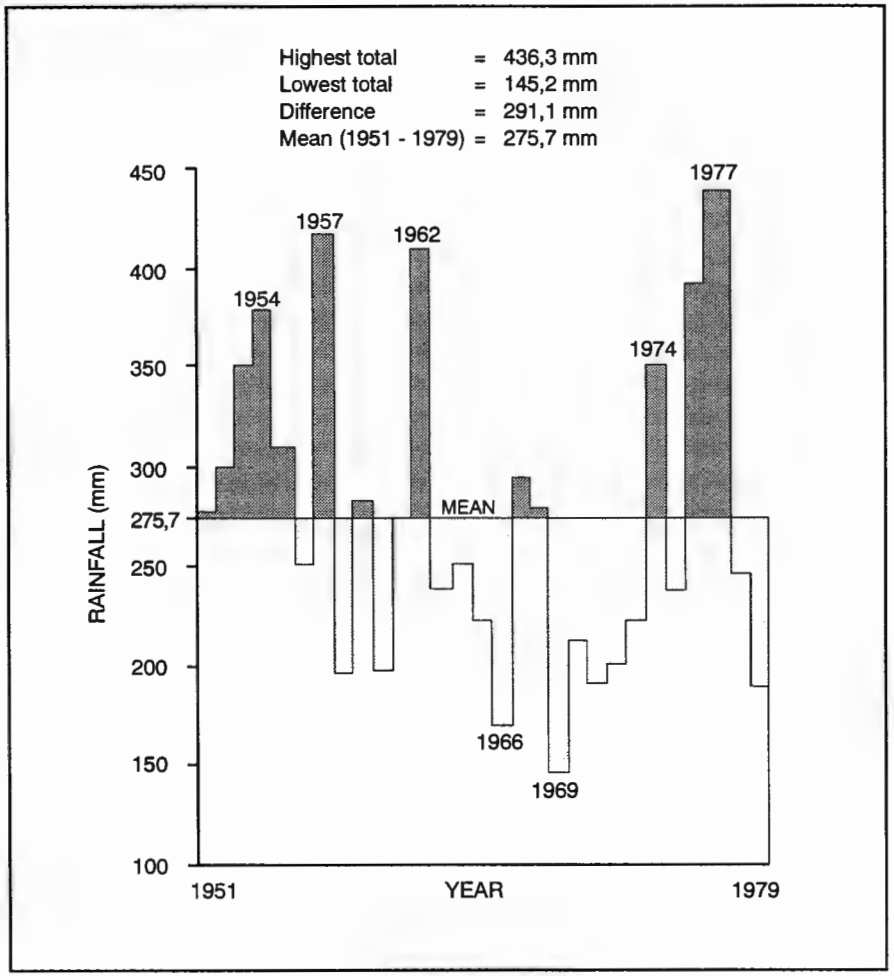


Figure 3.7 Annual rainfall data from Redelinghuys for the period from 1951 to 1979. Adapted from Robertson (1980).

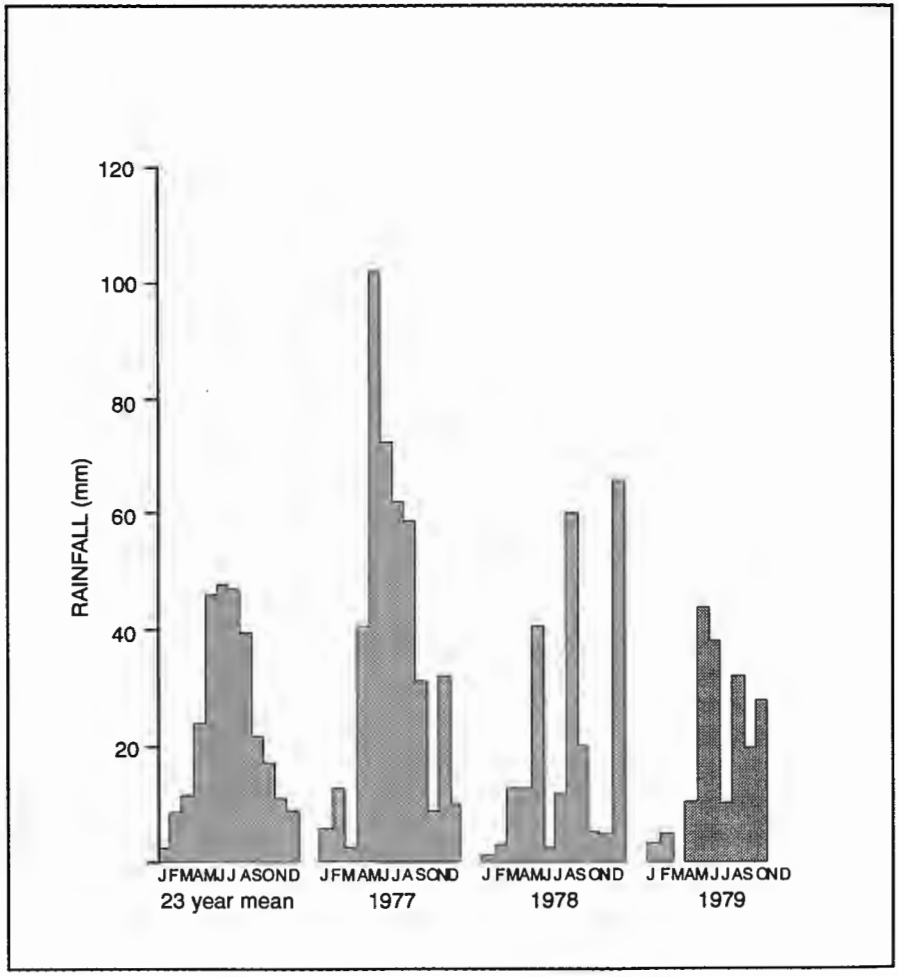


Figure 3.8 Monthly rainfall data from Redelinghuys. The 23 year mean is compared to the rainfall from 1977-1979. Adapted from Robertson (1980).

pressure belts, the centre of the frontal systems remains to the south of the Cape, even in winter and, as such, winter rainfall is confined to the southwestern Cape, becoming correspondingly lower and less reliable further northwards (Schultze and McGee, 1978). This latitudinal discrepancy in precipitation is not the only moisture gradient operative across the Sandveld. Implicit within Talbot's (1947) extensive rainfall observations, is the presence of a distinct precipitation gradient extending inland from the arid coastal strip towards the upland regions of the Swartland and the Cape Fold Belt to the east. This altitudinal moisture gradient is almost certainly the product of orographic intervention imposed on the frontal systems by the upland regions to the east of the Sandveld.

Robertson (1980) has compiled comparative rainfall data, spanning almost 30 years, from five meteorological stations within the Verlorenvlei catchment. An analysis of these data reveals that the average annual rainfall for the catchment amounts to 269.5 mm year^{-1}, and considering that the annual average for South Africa is 475 mm (Noble and Hemens, 1978), this northern extent of the Sandveld region may reasonably be construed as being semi-arid to sub-arid in nature (Bailey, 1979). Mean annual rainfall figures, such as those calculated above, tend to conceal the enormous variability inherent within seasonal and inter-annual precipitation. Figure 3.7 reflects the graphical representation of annual rainfall data from Redelinghuys for the period from 1951 to 1979. It is clear from the graph that the difference between the highest (1977) and lowest (1969) annual totals is greater than the average for the entire period under consideration. Similar variability may occur within the seasonal distribution of annual rainfall. Consider the monthly rainfall data from Redelinghuys for the years 1977 to 1979 (Figure 3.8). These rainfall data reveal that a rare rainstorm during December 1978, produced 71.5 mm in two days, thereby effectively concealing the occurrence of a marked winter drought, by elevating the mean annual rainfall to within proximity of the 23 year mean (Table 3.1).

(mm)	J	F	M	A	M	J	J	A	S	O	N	D	Total
23 yr mean	2.6	8.4	11.2	24.0	46.1	47.7	47.2	39.7	21.5	16.8	10.6	8.6	284.4
1979	2.8	4.6	-	10.0	43.6	37.8	9.5	32.0	19.5	27.5	-	-	187.3
1978	0.7	2.4	12.5	12.5	40.4	2.0	11.5	60.0	19.8	4.6	4.5	71.5	242.4
1977	5.5.	12.5	2.0	40.6	101.9	72.2	61.9	58.5	31.2	8.5	32.0	9.5	436.3

Table 3.1 Monthly rainfall variation at Redelinghuys for the period 1977 - 1979. After Robertson, (1980).

During the summer solstice, the track of the westerly pressure belts migrates 6° south and, with few exceptions, the impact of the frontal weather is confined to a narrow belt along the southern coast and to the Atlantic and Indian Oceans to the south of the continent (Tyson, 1986). A consequence of this southerly shift in the pressure belts is to align the South Atlantic Anticyclone at 31° S off the southwestern Cape coast. In turn, strong southerly to southeasterly gales are generated and these blow up and along the coast on an almost daily basis. The sparse cover (20 - 30 %) afforded by the indigenous Strandveld vegetation provides little protection to the mobile substrate, and considerable erosion of the sandy soils is attributable to this dominant summer regime (Lancaster, 1986). The southerly winds serve an additional function by driving the southern Benguela Upwelling System (Andrews and Hutchings, 1980). Under the combined influence of wind friction and Coriolus Force, the surface ocean waters are coerced off-shore, thereby instigating the upwelling of cold, nutrient-rich, sub-Antarctic bottom-waters in the near-shore coastal region (eg Cohen *et al.*, 1992). The presence of cold (8° - 9° C) Atlantic surface water along the coastal margin of the Sandveld during summer, acts to moderate temperature extremes, both annual and diurnal. Data derived from Cape Columbine (32° 50' S, 60 m amsl) records the annual temperature amplitude as 4.3° C and the daily temperature amplitude as 6.9° C. The February average maximum is 21.1° C and the July average minimum is 10.0° C (Butzer, 1979). Advective fog is common along the coastal margin, especially during the spring and autumn months, when the frequency and impact of the southeasterly summer gales are less pronounced. Although it is widely recognised that coastal fog is a valuable source of precipitation for coastal vegetation communities, the fog seldom penetrates any distance inland. Away from the coast, the moderating influence of the cold Atlantic is less profound, and temperature variations are considerably greater. Along the northeastern margin of the Sandveld, near Piketberg, summer temperatures in excess of 40° C are not uncommon and in winter, occasional light frosts may be experienced in sheltered valley bottoms (personal observation). The impact of summer aridity on available water resources is compounded by the high evaporative potential induced by the prevailing southeasterly winds. Measurements obtained from the evaporation gauging station at Lamberts Bay (32° 05' S) indicate the mean gross annual evaporation to be 1 400 mm or exactly seven times the average annual rainfall for the same station (Robertson, 1980). A census of mean annual pan evaporation data from other Sandveld recording localities indicates similar trends (Midgley and Pitman, 1969).

In a climatically variable, semi-arid environment such as the Sandveld, extreme weather events may be more important than average occurrences in determining the gross landscape morphology and associated ecological composition (Werger, 1978). This

conjecture seems even more appropriate when one considers the inherent fragility of Verlorenvlei and its immediate environment. Certainly, with regard to surface erosion within the catchment, hydraulic regulation of the fluvial-lacustrine system and the nature and composition of terrestrial and aquatic vegetation communities dependent upon the vlei, the sum of extreme weather events is envisaged to be critically significant. Despite their important role in developing and shaping landscapes into their modern form, it is seldom possible to elucidate the nature, range and frequency of former climatic extremes in the fossil record. The imprecision attached to palaeoecological research is such that a more generalised assessment of former climates is anticipated. In this regard it is expected that any palaeoclimatic interpretations that may arise from this study will be of a relative nature: identifying phases in the past which were comparatively moister or drier, warmer or colder - even seasonally divergent - with respect to the contemporary climate generalised for the Sandveld today.

3.2.4 Natural vegetation

The following account of the Sandveld vegetation is intended to provide an overview of the component communities, based on broad categorisations, that constitute the contemporary natural vegetation. It is important to consider that the natural vegetation has, during the past three centuries, been significantly altered by urban encroachment, cultivation, overgrazing and the introduction of alien invasive species (Bigalke, 1979; Jarman, 1986; Hilton-Taylor and le Roux, 1989). In this regard, it is difficult, if not impossible, to reconstruct the precise nature and extent of former natural vegetation within the major part of the Sandveld. As a consequence, regional interpretations of the natural vegetation have come to be based on remnant communities that are frequently isolated and, by implication, probably malnourished in terms of their richness and diversity (Jarman, 1986; Acocks, 1988). In view of the fact that this investigation is centred primarily in the Verlorenvlei region, towards the northern limits of the classical Sandveld, a detailed account of the local vegetation from this particular ecotone is considered to be of great importance - especially if the fluctuations in the vegetation of the past are to be understood.

Chorologically speaking, the vegetation of the Sandveld forms an integral component of the fynbos biome (or Cape Floristic Region), a larger phytogeographical delineation that includes most of the Cape Fold Belt and its attendant coastal lowlands (Figure 3.9). The considerable climo-edaphic variability inherent within the geography of the fynbos biome has ensured a high degree of floristic diversity (Cowling *et al.*, 1989).

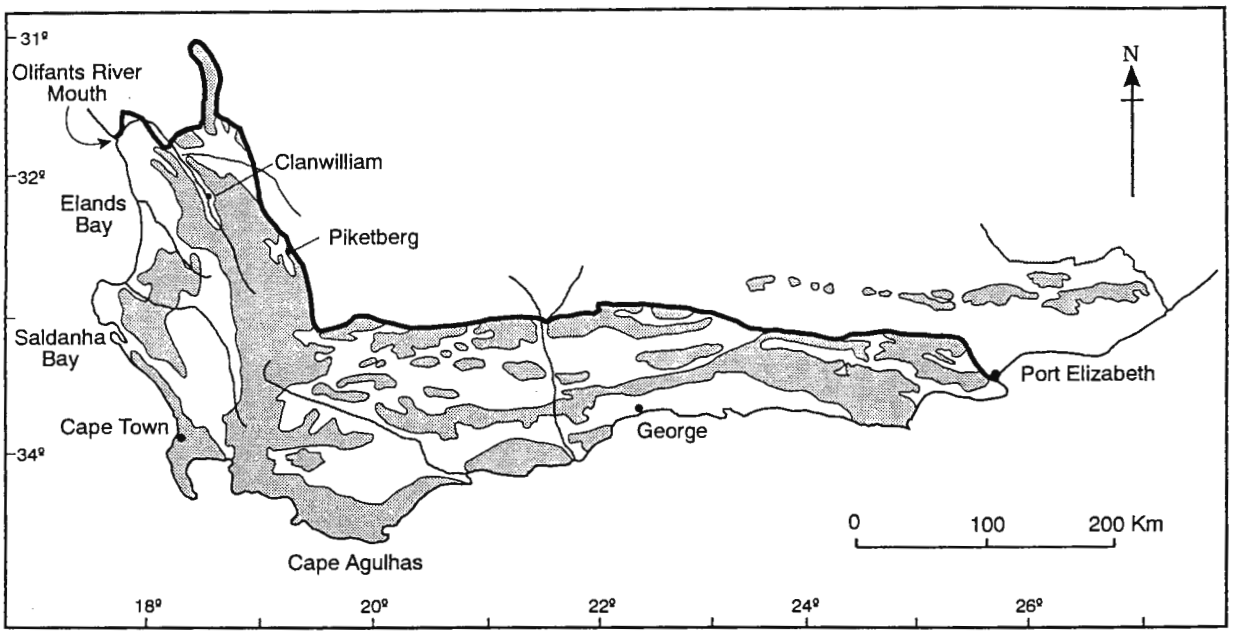


Figure 3.9 Location of the Cape Floristic Region (after Goldblatt, 1978). The shaded areas show the distribution of fynbos, a mosaic of plant communities dominated by elements of the Cape flora.

The biome occupies an area of some 90 000 km², less than 4 % of the area of southern Africa. Yet, despite its comparatively small geographical extent, this diminutive region hosts almost 50 % of the known plant species from the entire sub-continent (Bond and Goldblatt, 1984). The fynbos biome is to a large extent dominated by *fynbos* communities belonging to the so-called Cape Flora. Fynbos (pronounced '*fane-bos*') is a vernacular term used to describe the predominant sclerophyllous shrubland, particular to the southwestern Cape Province of South Africa (Acocks, 1988). Elsewhere in the world, vegetation of comparable floristic structure, referred to as Macchia, occurs in similar Mediterranean-type environments (Cowling and Campbell, 1980). With more than 8 500 species of flowering plants and gymnosperms and 75 species of ferns and other vascular plants, the fynbos is the richest known flora in the world (in terms of species per unit area) - richer even than the flora of the Amazon Basin (Jarman, 1986). Perhaps more significant than the high levels of species diversity and species richness (Kruger and Taylor, 1980; Huntley, 1989), is the remarkable degree of endemism exhibited by the fynbos. Almost 70 % of species and 20 % of genera are endemic to the fynbos biome, suggesting strong phytogeographic unity among the Cape Flora (Bond and Goldblatt, 1984). It should be mentioned here that the flora of southwestern western Australia offers by far the closest analogue for the Cape Flora, including many shared genera and families. The distinctive characteristics of the fynbos have come to be recognized among the hierarchical classifications of the world's major floristic regions (Good, 1947). Today the fynbos is regarded as one of only six global vegetation divisions, the Cape Floral Kingdom (Figure 3.10).

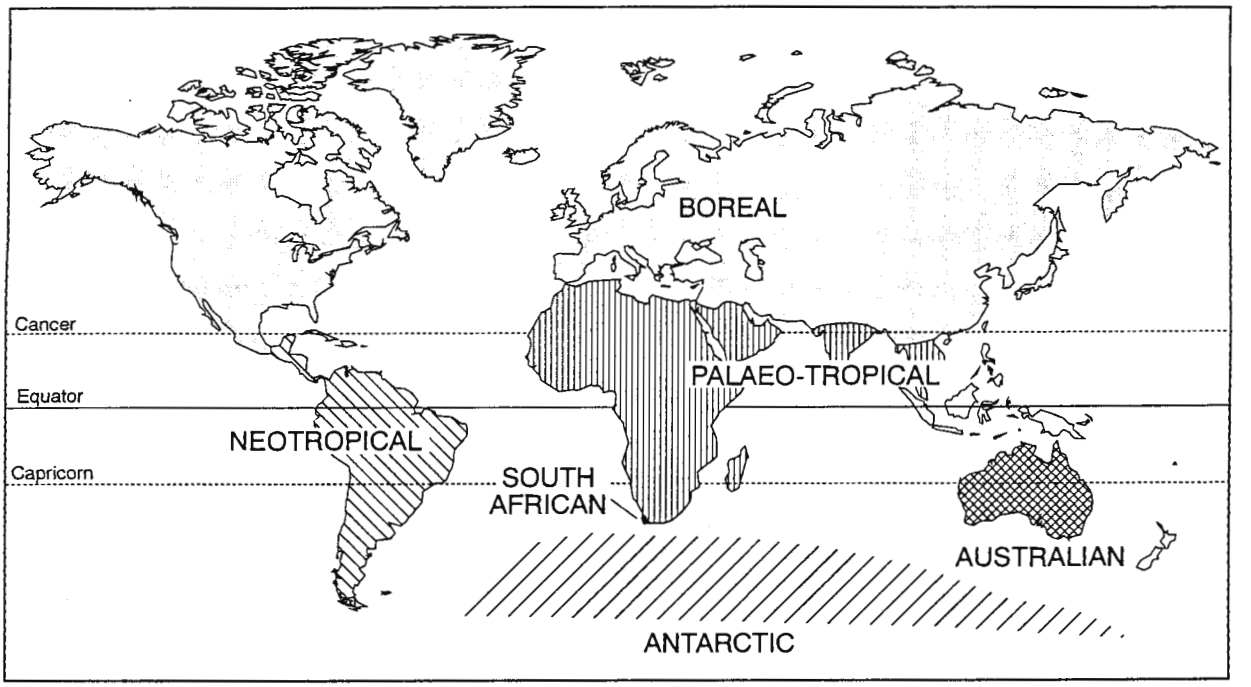


Figure 3.10 The six floristic kingdoms of the world. After Good (1947).

Despite the uniqueness and considerable scientific interest attached to the fynbos, it was not until the late 1970's, with the emergence of the Fynbos Biome Project that research activity first began to address rigorous floristic classifications and structural characterisations of the biome vegetation (Campbell *et al.*, 1984; Moll *et al.*, 1984). Taylor (1978) and Kruger (1979) were the first to publish reviews on fynbos ecology, followed by the major descriptive classification of Bond and Goldblatt (1984). Innumerable ecological research initiatives have since followed, culminating in the extensive review of fynbos ecology by Cowling (1992). These concerted efforts notwithstanding, the floristic complexity of the fynbos biome continues to pose a major challenge to the detailed typological assessment of the vegetation. Similarly, a number of studies have attempted to elucidate the origin and development of the fynbos through geological time. Despite vigorous efforts by Sugden (1989), the late Quaternary evolution of the fynbos remains somewhat enigmatic. Moll *et al.* (1984) and Jarman (1986) have described the major vegetation categories in and adjacent to the fynbos biome and these have been selected to differentiate, briefly, the vegetation types of the Sandveld.

Although the Sandveld falls within the geographical extent of the fynbos biome, the vegetation communities are not restricted solely to those of the Cape Floral Kingdom, but include elements of the Cape-Palaeotropic Floral Kingdom Transition, the Palaeotropic Floral Kingdom and various ecotonal assemblages (refer to Table 3.2).

VEGETATION CATEGORIES	ENVIRONMENTAL DESCRIPTION	BIOGEOGRAPHIC AFFINITY	FLORAL KINGDOM DIVISION
Cape Fynbos Shrubland			
Mountain Fynbos			
Dry Mountain Fynbos	Heathlands on sandstone quartzite mountains		
Lowland Fynbos		Cape Communities	**CAPE FLORAL KINGDOM**
Sand Plain Fynbos	Heathlands on lowland acid sands		
Limestone Fynbos	Heathlands on lowland limestone		
Mosaic of Cape Fynbos Shrublands and Subtropical Elements			
Dune Fynbos	Shrublands on coast dunes	Cape/Sudano-Zambezian Communities	
Cape Transitional Small-leafed Shrublands			
Renosterveld			
West Coast Renosterveld	Small-leafed shrublands on Malmesbury shales	Cape/Karoo-Namib Communities	**CAPE PALAEOTROPIC FLORAL KINGDOM TRANSITION**
Cape Transitional Large-leafed Shrublands			
Strandveld			
West Coast Strandveld	Broad-leafed shrublands on coastal calcareous sands	Tonga/Pondoland/Cape/ Karoo-Namib/Community	
Subtropical Transitional Thicket			
Afromontane Forest			
Afromontane Forest communities	Undifferentiated	Afromontane Community	**PALAEOTROPIC FLORAL KINGDOM**
Karroid Shrublands			
Karroid Shrublands	Undifferentiated. On shales mudstones	Karoo-Namib Community	
Ecotones:	- Mosaic of Dry Mountain Fynbos and Karroid Shrublands - Mosaic of Sand Plain Fynbos and West Coast Strandveld - Mosaic of Dune Fynbos and West Coast Strandveld - Mosaics of partially cleared agricultural land		
Azonal Communities:	- Riverine Communities - Wetland Communities - Littoral Communities		

Table 3.2 Major vegetation categories recognised from the Sandveld. After Moll *et al.* (1984).

The Sandveld vegetation communities which belong to the Cape Floral Kingdom include: i) Dry Mountain Fynbos (which occurs along elevated sandstone outliers of the Cape Fold Belt, such as Piketberg), ii) Sand Plain Lowland Fynbos (which is ubiquitous among the deep acid sands south of Elands Bay) and, iii) Limestone Lowland Fynbos (which occurs among isolated patches of calcrete near Saldanha Bay). The communities belonging to the Cape-Palaeotropic Floral Kingdom Transition include: i) West Coast Renosterveld (restricted to the Swartland-Sandveld interface among the fine grained soils derived from Malmesbury phyllites and Cape granites), ii) West Coast

Strandveld (which extends along the coastal margin, preferring the alkaline soils) and, iii) Dune Fynbos (which occurs among calcareous sands along the coastal margin). The vegetation communities of the Palaeotropic Floral Kingdom include: i) Afromontane (Scrub) Forest (woody elements preferring sheltered south-facing ravines among the sandstone koppies) and, ii) undifferentiated Karroid Shrublands (including the Semi-Succulent Karoo of the Namaqualand coast). In addition to these distinctive sub-divisions, transitional vegetation communities have developed along environmental boundaries (ecotones) to form so-called vegetation 'mosaics'. For example, the Mosaic of Sand Plain Fynbos and West Coast Strandveld (Boucher, 1983). This latter admix of communities, which accounts for a considerable proportion of the Verlorenvlei area, cannot be separated owing to complex local edaphic factors which appear to play a deterministic role in the distribution of the component vegetation types (Grindley *et al.*, 1982). In addition to the predominant terrestrial vegetation, various Azonal Communities exist, including Riverine, Wetland and Littoral communities.

3.2.4.1 *Biogeography of the major vegetation categories*

The remainder of the section will be dedicated to a biogeographical description of each of these component categories. Useful botanical information has been gathered from: Talbot (1947), Mason (1972), Werger (1978), Boucher (1980), Grindley *et al.* (1982), Boucher (1983), Bond and Goldblatt (1984), Sinclair *et al.* (1986), Grindley and Grindley (1987), Acocks (1988), and from field observations conducted in the company of various botanists including Dr T Hoffman from the National Botanic Institute at Kirstenbosch.

The physical setting of Verlorenvlei is unique within the Sandveld insofar as it represents a diverse and complex interface between the cold upwelling Atlantic Ocean, the arid coastal plain and the fresh water river, lake and wetland system. The terrestrial environments which extend inland from Elands Bay occupy the northern extent of the classical Sandveld and are considered to be ecotonal with respect to the Capensis and Karoo Namib phytogeographical regions to the south and north respectively (Taylor, 1978; Acocks, 1988). The structural and physiognomic variability of the Verlorenvlei area together with its juxtaposition along the ecotone between the Lowland Fynbos, Strandveld and Karroid Shrubland communities, has ensured a complex mosaic of different vegetation types and a high degree of floristic diversity. The original mixing of these vegetation types is envisaged to have been the product of fluctuating climates (probably rainfall) during the late Quaternary and this hypothesis, among others, forms the objective of this investigation. The present distribution of the Sandveld vegetation

mosaic remains closely linked to local edaphic, relief and aspect factors (Grindley *et al.*, 1982).

The botanical importance of the Verlorenvlei area has come to be widely recognised (Acocks, 1988; Taylor, 1978; Grindley *et al.*, 1982; Boucher, 1983; Moll and Bossi, 1984). Following extensive botanical surveys, soil mapping and satellite imagery (Lane, 1980), Sinclair *et al.* (1986) were able to produce a provisional vegetation map of the Verlorenvlei catchment (Figure 3.11) which portrays the hypothetical distribution of natural vegetation under the scenario of a pristine environment (ie in the absence of cultivation and livestock overgrazing). In total, nine distinct vegetation types have been mapped for the Verlorenvlei catchment and although their modern distribution is restricted by comparison to Sinclair *et al.*'s hypothetical projection, all nine vegetation types are present, in varying proportions, in the region today. A modified list of the Verlorenvlei vegetation is presented below.

1. **West Coast Strandveld**	4. **Dry Mountain Fynbos**
i) Dune Strandveld	i) Afromontane Forest
ii) Shrubby Strandveld	5. **Marsh Vegetation**
iii) Restioid Strandveld	i) Saltpan Vegetation
2. **Lowland Sand Plain Fynbos**	ii) Riparian Vegetation
3. **Karroid Shrubland**	iii) Aquatic Vegetation

1. **West Coast Strandveld.** In general, the West Coast Strandveld (Acocks (1988), refers to this as Strandveld Proper) applies to those non-fynbos, broad-leafed sclerophyllous communities that occupy the alkaline to neutral sands of the coastal dunes and peripheral sand flats (Lane, 1980). At Verlorenvlei, the physiognomic integrity of the West Coast Strandveld becomes confused by the presence of elements from the Cape and Karoo-Namib floras (Grindley *et al.*, 1982) as well as certain Afromontane species, confirming the region to be in close proximity to an important ecotonal boundary. The overall appearance of the West Coast Strandveld is that of an open, semi-succulent scrub, with distinct shrubby clumps ranging in height from 1 - 2 m. A variety of smaller bushes, herbs and grasses is interspersed among the larger shrubs. Characteristic genera include *Salvia, Zygophyllum, Ruschia, Lebeckia, Pteronia, Lycium, Euphorbia, Galenia, Wiborgia, Aspalathus, Hermannia, Nylandtia, Eriocephalus* and *Willdenowia* (Acocks, 1988).

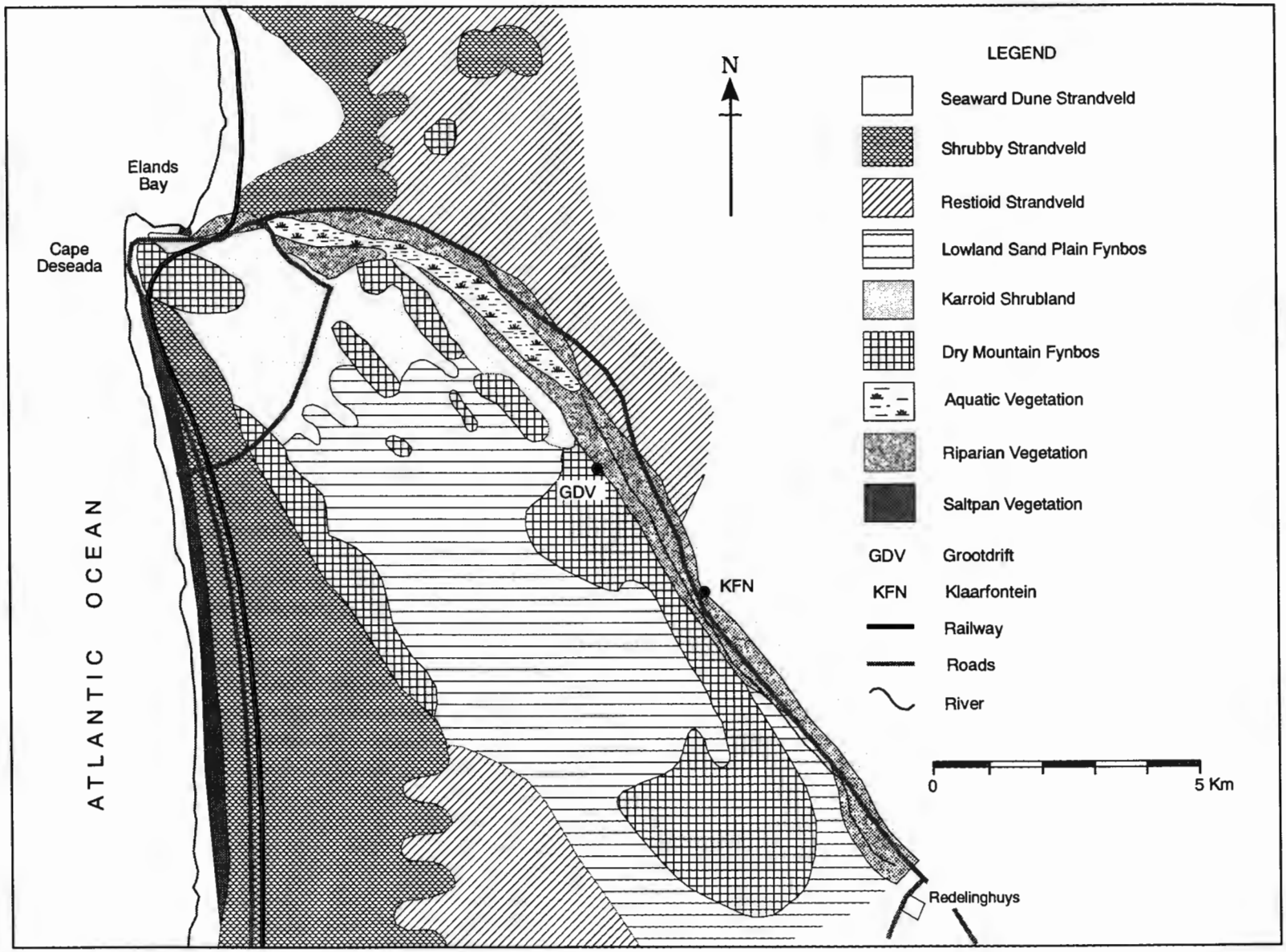


Figure 3.11 Vegetation of Verlorenvlei and Sandveld environs. Adapted from Sinclair *et al.* (1986).

Boucher and Jarman (1977) have distinguished three inter-grading subdivisions of West Coast Strandveld and these are termed Seaward Dune Strandveld, Shrubby Strandveld and Restioid Strandveld. Essentially, these subdivisions reflect edaphic and structural changes along an environmental gradient that extends from the littoral dunes at the coast to the deep acid sands that herald the transition to Lowland Fynbos. Among the Seaward Dune Strandveld, pioneer vegetation dominates and succulence is prevalent. Characteristic plants include: *Didelta carnosa, Hebenstreitia cordata, Carpobrotus* spp., *Senecio maritimus, Senecio elegans, Eragrostis cyperoides, Ehrharta villosa* and *Tetragonia* spp. Inland of the littoral dunes, broad-leafed sclerophyll shrubs up to 2.5 m are common, especially in damp troughs and along west-facing slopes where advective fog provides supplementary precipitation. Among these larger shrubs, geophytes, grasses and annual herbs contribute to the overall ground cover which fluctuates seasonally, reaching a maximum of 40 % during winter. Characteristic species include evergreen shrubs such as *Rhus* spp., *Euclea racemosa, Diospyros* spp., *Colpoon compressum*, the spinescent *Maytenus* spp. and drought-deciduous genera such as *Lebeckia, Lycium, Zygophyllum, Salvia* and *Eriocephalus*. Bush clumps are frequently entangled with creepers including *Galium, Kedrostis* and *Microloma*, while succulents such as *Euphorbia* spp., *Crassula, Tylecodon* and *Mesembryanthemum* spp. abound. The geophytes *Trachyandra, Lachenalia* and *Antholyza*, together with grasses such as *Pentaschistis* and *Ehrharta* spp., constitute the seasonal ground cover. On reaching the leached acid sands, away from the influence of the coast, Strandveld inter-grades with Lowland Fynbos to form a transitional community referred to as Restioid Strandveld (Sinclair *et al.*, 1986). The most significant feature of this vegetation type is the dominance of *Willdenowia* spp., a restioid element, at the expense of drought-deciduous, thorny and succulent shrubs. An extensive tract of Restioid Strandveld occurs along the northeastern margin of the vlei and extends north towards Lamberts Bay.

2. **Lowland Sand Plain Fynbos.** At Verlorenvlei, this type emerges from the Strandveld and karroid communities to dominate the deep acid sands of the interior lowlands and is especially common among the recessed plains, to the southwest of the sandstone krantzline. Restionaceae are the most abundant element among the vegetation (comprising some 50 - 60 % of the total vegetation cover) while Proteaceae and ericoid shrubs contribute to the overall fynbos appearance (Taylor, 1978). Drought-deciduous and succulent plants, prevalent in the Strandveld and karroid vegetation types, continue to be represented in the Lowland Fynbos, but are comparatively less diverse. Grasses are notably less abundant in the Lowland Fynbos, indicating that the predominant *Willdenowia* spp. are better-suited to the graminoid role among the acid substrate. Although many of the characteristic Strandveld genera persist in the Lowland Fynbos, the

presence of genera such as *Dodonea, Brunsvigia, Lessertia, Stoebe, Maytenus, Diospyros, Leucodendron, Leucospermum, Serruria, Aspalathus, Phylica, Metalasia, Passerina, Chondropetalum, Grielum* and *Anthospermum*, among others, contribute to a distinctive fynbos flavour.

3. **Dry Mountain Fynbos**. (Dry) Mountain Fynbos has a strong edaphic affinity to the substrate derived from the sandstones of the Table Mountain Group. This vegetation type is therefore strongly correlated to the prominent sandstone krantzline, situated to the southwest of Verlorenvlei, and to the Cape Fold Belt outliers that constitute the source of the catchment. By comparison to Mesic Mountain Fynbos, typical of the southern Cape Fold Belt, the levels of diversity and richness among the Dry Mountain Fynbos of the Sandveld are notably depauperate (Cowling *et al.*, 1989; Linder 1991). Nonetheless, an authentic fynbos identity is confirmed for the Sandveld mountains by the presence of restioid, proteoid, ericoid and geophytic elements, the four major fynbos growth forms. Structurally and floristically, the Dry Mountain Fynbos has much in common with the Arid Fynbos types described by Taylor (1978) and Boucher (1980). Along dry exposed slopes, vegetation is characteristically small-leafed, drought-deciduous and succulent, whereas shady cliffs and gullies tend to support evergreen shrubs and woody tree elements (Grindley and Grindley, 1987). Among sandy soils, especially along the margins of Piketberg, sclerophyll elements increase to include *Phylica* spp., *Passerina glomerata, Stoebe* spp., *Struthiola, Thesium, Aspalathus* and *Helichrysum*. Those species demonstrating an affinity to sheltered cliffs and gullies, locations which abound among the rocky outcrops near Verlorenvlei, generally include woody shrubs such as *Leucadendron pubescens, Protea laurifolia, Dodonea viscia, Maytenus oleoides, Rhus undulata, Phylica oleoides, Heeria argentea, Diospyros glabra, Solanum incanum, Euryops abrotanifolius, Buddleja* spp. and *Salvia* spp. Peripheral vegetation includes geophytes such as *Babiana* and *Velthemia* and Mesembs such as *Conophytum* and *Carpobrotus*.

Of considerable botanical interest is the possibility of an Afromontane Forest component at Verlorenvlei. In general, this component is not well represented among the contemporary Sandveld vegetation and its delineation here may be somewhat surprising. However, a few isolated Afromontane-type (Scrub) Forest refugia have been encountered among the sheltered south-facing ravines of the Verlorenvlei krantzline and the Piketberg massif (personal observation) Although difficult to separate from the Dry Mountain Fynbos, it is possible to distinguish a distinct forest component from the following species: *Olea capenis, Maytenus acuminata, Heeria argentea, Myrica serrata* and the 'indicator' specimen, *Podocarpus elongatus*. This latter species, the Breede

River yellowwood, reaches its extreme westerly distribution at Verlorenvlei, normally preferring the well-watered mountainous ravines of the southern and southwestern Cape Fold Belt (Bond and Goldblatt, 1984). The presence of these stunted Afromontane-type elements, among the hostile Sandveld environment, is highly significant and prompts the questions: i) Under what climatic regime and at what point in time did these Afromontane elements arrive in the Sandveld? ii) Are they relicts of a former more widespread occurrence or, iii) are they recent arrivals? The answers to these questions form one of the many objectives of this study.

4. **Karroid Shrubland.** This broad vegetation category is used to describe all non-fynbos, Karoo-related communities that constitute the remaining Sandveld vegetation (Grindley and Grindley, 1987). Coincidentally, these communities are all confined to the shaley lower slopes of sandstone koppies, such as Bobbejaansberg, where the clay and weathered mineral content is evidently higher. The major components of the Karroid Shrublands are indicated as Karroid Brokenveld and Succulent Karoo (Acocks, 1988). As with the transitional Strandveld, drought-deciduous woody dwarf shrubs and succulents dominate these veld types. Typical generic content includes *Athenasia, Galenia, Hermannia, Pteronia, Zygophyllum, Protasparagus, Crassula, Tylecodon, Carpobrotus, Euphorbia, Elytroppapus, Ruschia, Eriocephalus, Senecio, Felicia, Grielum* and *Lebeckia*. Mixed affiliations of annual grasses and geophytes provide seasonal cover and grade across into the neighbouring Dry Mountain Fynbos communities. These elements include *Aizoon, Oxalis* spp., *Cynodon, Manulea, Haemanthus, Arctotheca, Sutera* and *Romulea*. Curious vegetation patterns have developed in response to the calcareous heuweltjie formations that punctuate the otherwise oligotrophic soils of the Sandveld (Knight *et al.*, 1989). Owing to their elevated clay content, heuweltjie soils are able to support deciduous karroid vegetation such as *Didelta spinosa, Rhus dissecta, Zygophyllum morgsana, Tetragonia fructcosa* and *Euphorbia* spp. These prominent karroid indicators are readily conspicuous among the otherwise uniform fynbos communities to such an extent that the general landscape takes on a distinctive, measled complexion. This perception is reinforced among informal pasturage (for example, behind Uitkykberg) where the centres of the heuweltjies are frequently dominated by a single, large evergreen shrub such as *Euclea undulata* or a succulent such as *Euphorbia caput-medusae* (personal observation) - seemingly at the expense of other palatable vegetation. The nutrient enhanced and pH altered soils are also popular habitats for alien invasive species, the most common being *Acacia cyclops* (Grindley and Grindley, 1987).

5. **Marsh Vegetation.** Marsh vegetation is composed of semi-aquatic elements which are common to, Riverine, Wetland, Littoral and Azonal Communities. The vegetation components grade naturally into one another along two environmental gradients at Verlorenvlei. The first is a salinity gradient, conventionally extending from hypersaline conditions at the distal marine interface to fully fresh water conditions in the proximal river environments. The second gradient extends laterally and corresponds with available water (depth), either as surface water (which may reach 5 m in the centre of Verlorenvlei), or as the subterranean water table (which fluctuates seasonally and declines with increasing distance from the vlei margin).

In the Sandveld, the best example of Saltpan vegetation may be found among the extensive mudflats of Langebaan Lagoon (Day, 1981). At Verlorenvlei, typical saline to hypersaline marshy areas occur towards the channel mouth, in the dune slack south of Cape Deseada and inland of the seaward dunes at Wadrifsoutpan (32° 12' 15" S; 18° 19' 40" E). Along these muddy saline flats, dense mats of low-growing halophytic vegetation have developed. The composition of these communities may fluctuate in response to salinity but are comprised largely of Chenopodiaceae (including *Chenolea, Salicornia* and *Sarcocornia*). In close association with the Chenopods, *Limonium, Cotula, Onixotis, Aizoon*, and *Mesembryanthemum* spp. occur in varying proportions. The grasses *Sporobolus virginicus, Cynodon dactylon* and *Diplachne fusca* demonstrate saline tolerance while reeds such as *Scirpus, Juncus* and *Triglochin* are especially common along the open water fringe. In Verlorenvlei, away from the immediate influence of the coast, a decline in salinity to less than twenty parts per thousand corresponds with an increase in reed-type vegetation (personal observation). *Scirpus maritimus* and *Juncus kraussii* dominate along the vlei margins near Bonteheuwel farm, while the 'fluitjiesriet', *Phragmites australis* is pervasive among the variable shallow waters of the Verlorenvlei Farm embayment, extending into the open water to a depth of between 1 - 1.5 m. *Phragmites* reeds are able to tolerate a wide range of salinities and occur along the length of Verlorenvlei, where their landward growth is limited by water availability during summer (Robertson, 1980). In less saline areas of Verlorenvlei, the bulrush or colloquial 'papkuil', *Typha capensis,* forms a fringe along the landward side of *Phragmites* stands where seepage from fresh water springs is seen to act to their advantage. Interspersed among the *Typha* skirt, sedges such as *Cyperus marginatus, Cyperus fastigatus* and *Mariscus thunbergii* form close associations with *Scirpus* and *Juncus* elements, especially among perennially moist environments. Upstream of the major embayment, towards Grootdrift Farm, a distinct hydrosere transformation is evident as dense stands of *Phragmites*, indicating the present extent of the open water, merge into the *Typha*-dominated river valley that extends inland towards Redelinghuys.

The Aquatic vegetation component within Verlorenvlei is variable and its composition and distribution is closely linked to seasonality and salinity. The euryhaline eelgrass, *Zostera capensis*, is the most common submerged aquatic macrophyte in the saline and hypersaline ponds that develop near the mouth of Verlorenvlei during summer. *Potamogeton pectinatus* occurs in the lower regions of the vlei, but is absent from sites higher up in the system (J Grindley, personal communication), suggesting that it prefers a moderate saline habitat. *Myriophyllum spicatum* ('parrot's feather' - an indigenous sub-aquatic macrophyte), is found in abundance in the slow flowing open water regions of the embayment, where it is frequently grazed by cattle and horses (Robertson, 1980). In the upper reaches of the vlei and in stagnant riverine pools, floating macrophytes ('wateruintjies') such as *Aponogeton angustifolius, Nymphoides indica* and *Nymphaea capensis* form colourful displays.

3.2.5 Modern land use practices

With the exception of those regions mantled by richer shale-derived soils, the majority of the Sandveld is considered to be of only marginal agricultural potential. Despite their unsuitability as wheat-growing areas, substantial tracts of Sand Plain Lowland Fynbos and West Coast Strandveld were cleared for agriculture during the grain boom of the 1920's. Due to recurrent crop failures, especially along the semi-arid coastal margin, many of these cultivated fields have since been abandoned and left for casual pasturage. These areas, together with the remaining tracts of natural open veld, have endured 60 - 70 years of selective grazing by cattle, sheep and goats. Within the Verlorenvlei catchment, Sinclair (1980) has traced the historical development of land usage in relation to land-ownership from archival records. From a more recent perspective, useful graphic information may be derived from orthophoto maps and air photographs of the region which clearly delineate the extent of agricultural clearance, overgazing and human settlement. With the exception of the upper reaches of the Kruismans River near Eendekuil, where extensive rolling wheatlands have consummately replaced the natural Renosterveld vegetation, formal agriculture has, until recently, been limited to those sandy areas to the south of the vlei where Lowland Fynbos has been strip-cleared for winter wheat cultivation. To the north and inland of Verlorenvlei, the predominant Strandveld vegetation has generally escaped clearance by serving as informal pasturage. However, the recent introduction of mobile, mechanised irrigation systems has had a profound effect on agricultural development in the Verlorenvlei area, especially during the last decade (Pomuti, 1995). Where previously, irrigable crops were restricted to the alluvial margins in close proximity to the river and vlei, new technology

indiscriminate clearing of vast tracts of natural vegetation with little consideration for the environment. Indeed, the alacrity with which local stock farmers have converted to cash crops such as potatoes and lucerne has contributed to a number of serious environmental disorders. These include the uncontrolled abstraction of water from the upper regions of Verlorenvlei and the primary Elands Bay aquifer (Maclear, 1994), the introduction of pesticides, herbicides and artificial fertilizers to the sensitive wetland system, the widespread problem of soil salinisation and accelerated soil erosion (personal observation), and the concomitant siltation of the Verlorenvlei embayment (Baxter and Davies, 1994). With the burgeoning number of centre-pivot irrigation systems currently being deployed in the Verlorenvlei region, it is urged that cognisance be taken of the recommendations put forward by the Verlorenvlei Omgewings-taakgroep (1993).

3.3 Location and description of specific study sites

One of the major incentives behind the initial decision to proceed with a palaeoenvironmental investigation at Verlorenvlei, was the premise that the wetland environment would prove to be an ideal receptacle for the collection and preservation of pollen produced by the local (Verlorenvlei) and regional (Sandveld) vegetation. Preliminary investigations, conducted at the onset of the study, revealed the preservation of fossil pollen, in varying degrees, in a range of depositional environments including: spring sites, marsh environments, fluvial deposits, lacustrine deposits, archaeological sites, soil profiles and even hyracium middens. To begin with, the primary sampling strategy was concentrated in the wetlands, and coring for polleniferous sediments commenced at a number of different locations. Additional cores, for the purposes of sedimentological analyses, were also derived from the Verlorenvlei system. During the latter half of the study, the focus of the investigation shifted away from the immediate confines of the wetland and sought to assess the palynological record from archaeological sites within the Sandveld. The following section is intended to introduce the reader, by means of a brief biogeographical description, to each of the six primary study sites (refer to Figure 3.3).

1. **Grootdrift Farm.** Following an extensive reconnaissance of the lower Verlorenvlei catchment, the wetland sediments on Grootdrift Farm were identified as having investigative potential. The farm is located in the main Verlorenvlei valley (32° 23' 79" S; 18° 27' 10" E), 15 km from Elands Bay and 10 km west of Redelinghuys. Immediately upstream of Grootdrift, the Verlorenvlei river emerges from a narrow, incised valley and radiates out to form an extensive wetland, dominated by swards of *Typha*

and *Phragmites* reeds. Closer inspection reveals that an alluvial delta has developed at Grootdrift, effectively maintained and concealed by the dense association of reeds and riparian vegetation. A subterranean dike intersects the vlei at this point and contributes to the muddy alluvial sponge, which extends laterally for 500 m across the valley floor before merging with the main embayment of the estuarine lake at Diepkloof. The location of Grootdrift is thus seen to be transitional with respect to the Verlorenvlei river and the estuarine lake. Fallow agricultural fields line both sides of the Grootdrift wetlands and extend down to the riparian zone. Recessed behind the fields on the southwest bank, Dry Mountain Fynbos shrubs including *Ficus cordata, Aloe* spp., *Solanum, Euryops, Rhus undulata* and *Crassula* cling tenaciously to the overgrazed and exposed slopes of the krantzline. To the northeast of the vlei, Restioid Strandveld and Karroid Shrubland dominate the rolling topography. In the vlei, standing pools of lentic water support *Nymphoides* and *Aponogeton*, while a rich variety of avifauna congregate among the reeds. The Grootdrift site is considered to be an ideal collector of local pollen derived from the catchment by fluvial transport and of regional pollen, conveyed to the site under the influence of the prevalent southeasterlies.

2. **Klaarfontein Spring**. Following the Grootdrift investigation, a series of artesian springs on the farm Klaarfontein (32° 25' 26" S; 18° 29' 40" E) was identified as a supplementary source of organic sediments. Located approximately 3 km upstream from Grootdrift, the Klaarfontein Springs are tucked away in an inconspicuous valley alcove among the rolling hills on the northeastern shore of Verlorenvlei. The principal spring feeds a small perennial stream and marsh system that drains perpendicularly to the Verlorenvlei River. Somewhat below the elevation of the Elands Bay road, three supplementary springs breach the surface and contribute to the boggy colluvial-alluvial marsh that protrudes towards an indistinct junction with the Verlorenvlei River. The lobed marsh remains perched above the river and is mantled by reeds and sedges including: *Typha latifolia, Juncus kraussii, Cyperus fastigiatus, Cyperus marginatus and Scirpus fluvitans,* while *Phragmites australis* occupies the deeper standing water along the vlei transition. *Zantedeschia aethopica* (arum lilies) are abundant in and around the source of the springs. Most of the indigenous Strandveld vegetation has been cleared from around the springs to make way for cultivated fields. Beyond the perimeter of cultivation, Restioid Strandveld has merged with Karroid Shrubland to produce a scruffy mosaic dominated by spinescent shrubs, unpalatable succulents and a scatter cover of *Willdenowia incurvata*. Water is implicit in the name of the farm Klaarfontein (fountain), and the primary decision to locate here was undoubtedly a consequence of the valuable source of fresh, potable water. Colonial farmers first settled at Klaarfontein in the late 18th century (Sinclair, 1980), raising the question of possible anthropogenic

disturbance among the spring sediments. In view of possible disturbance, an extensive preliminary coring investigation of the Klaarfontein site was conducted in order to satisfy the requirements for an undisturbed sedimentary sequence.

3. **Muisbosskerm se Groot Sloot.** The farm Muisbosskerm (32° 08' 28" S; 18° 18' 32" E) is situated off the coast road, some 5 km south of Lamberts Bay and immediately opposite the renowned seafood eatery of the same name. The farm extends inland from the primary dune cordon and south along an extensive depression in the direction of Elands Bay. Although the dune cordon itself is sparsely vegetated by succulent elements of the Seaward Dune Strandveld, most of the dune vegetation and Shrubby Strandveld has been cleared for the production of potatoes and winter wheat. The investigation at Muisbosskerm se Groot Sloot (Muisbosskerm's large trench) was prompted more by opportunity than design. Following a trench digging exercise by the farmer, in preparation for the laying of a pipeline, a substantial linear excavation to a depth of 2 m was carved across the depression behind the primary coastal dune cordon. On closer inspection it was revealed that the basal deposits of the excavation were of a dense, fibrous peaty nature and differed markedly in their texture and composition when compared to those sediments located towards the surface of the deposit. From the stratigraphy and macrophytic remains, it became clear that the exposed dune depression was once a highly productive, probably semi-aquatic environment, capable of supporting dense stands of reeds such as *Typha* and *Phragmites*. Given that the depression is now inundated and capped by littoral sands, an explanation for this pronounced environmental perturbation presented an additional challenge to the palaeoenvironmental reconstruction of the Sandveld.

4. **Spring Cave.** Spring Cave (32° 19' 17" S; 18° 19' 48" E) is an inconspicuous archaeological shelter situated at the base of a series of steep sandstone cliffs on Bobbejaansberg. From the raised beach, immediately west of the Verlorenvlei mouth and south of the Sishen-Saldanha railway line, a steep boulder-strewn slope, extends up towards the cave which is elevated at some 90 m amsl. From a distance, a distinct clump of green vegetation distinguishes the terrace immediately in front and to the right of the shelter. This floral beacon serves to advertise the presence of a water seep from a thin sandstone fissure at the rear of the cave. Within the shelter, ferns, mosses and herbs owe their existence to this perennial water source, which would have provided a vital resource for hunter-gatherers. The vegetation surrounding the cave contains elements of Dry Mountain Fynbos, Afromontane Scrub Forest and Karroid Shrublands. A large conglomeration of restios occupies the damp area in front of the cave while *Rhus, Zygophyllum, Carpobrotus, Tylecodon, Protosparagus, Pelargonium* and *Atriplex* make for

a diverse mixture of vegetation in the immediate vicinity. The domed entrance to the cave, which measures some 20 m across by 5 m in height, faces due north with a commanding view across Elands Bay and the mouth of Verlorenvlei. This alignment is expected to have an important bearing on the mechanism by which pollen is deposited in the cave. During the long dry summer months, strong winds prevail from the southeast. Given the protected aspect of the cave, these winds, which effectively blow along the length of the Sandveld, are not expected to contribute significantly to the pollen in the cave. On the other hand, the cave is directly exposed to the winter northwesterlies and these winds are expected to be the major contributor of atmospheric pollen. It is anticipated that the Spring Cave sequence will be well represented by pollen from both the coastal communities and the assorted vegetation of the Bobbejaansberg amphitheater.

5. **Elands Bay Cave**. There are only two long-sequence archaeological sites known from the West Coast region of the Sandveld. Besides the much-publicised site of Elands Bay Cave, the second noteworthy shelter is that of Diepkloof Cave, located some 15 km inland, near the Grootdrift transition (see Parkington and Poggenpoel (1987) for an account of Diepkloof Cave). Elands Bay Cave, as the name implies, occupies an elevated vantage point along the sentinel cliffs of Baboon Point, overlooking Elands Bay and the Atlantic Ocean. In many respects, Elands Bay Cave shares the biogeographical features of the neigbouring Spring Cave. Both caves are situated along Bobbejaansberg, both have a north-facing aspect and, as such, both caves have a similar sampling jurisdiction. The most striking difference between the two sites is their relative distance from the sea shore. While Spring Cave is recessed and considerably elevated above the modern shoreline, Elands Bay Cave is perched at 42 - 45 m amsl, virtually on top of the rocky platform at Cape Deseada. The marine influence is evident among the local vegetation which exhibits many halophytic species including succulents and woody shrubs, typical of Seaward Dune Strandveld. From Elands Bay Cave, a series of imposing sandstone cliffs stretches southwards, trending parallel to the coast and rising to a height of 160 m amsl. Among the cliffs and gullies around Waterkloof, woody Afromontane Scrub Forest elements such as *Ficus, Olea, Maytenus, Rhus, Heeria, Putterlickia* and *Euclea* combine with fynbos and Strandveld elements. The presence of these woody species among the sheltered sandstone water-courses implies that a favourable microclimate may exist along the coastal margin where advective fog provides additional moisture and regulates ambient temperatures.

6. **Verlorenvlei Farm embayment**. Given the distinct probability that mid-Holocene sea-level fluctuations, reported by Yates *et al.*, (1986) and Miller *et al.*, (1993) from the

West Coast, would have had a profound effect on the estuarine dynamics of Verlorenvlei, an opportunity was sought to investigate the sedimentary record from the lower reaches. In general, access to Verlorenvlei is restricted at the proximal end by the pervasive reed beds, while coring in the open water embayment would require the services of a pontoon and specialist coring equipment. Towards the distal, estuarine end of the lake, the open water converges at Skietkop. Here the vlei bifurcates, expanding to fill the natural embayment off Boekpenskop - site of the historic farm; Verlorenvlei (Sinclair, 1980). Extensive reed beds have assembled along both sides of the vlei, interrupted by sinuous channels and mudbanks in the shallow water. During prolonged periods of drought, the water levels recede to the point where it becomes possible (albeit arduous) to wade out towards the reed beds in order to sample the muddy sediments. The fortuitous exposure of the shallow embayment off Verlorenvlei Farm therefore presented a unique and expedient opportunity to sample the estuarine sediments from Verlorenvlei.

3.4 Conclusions

A thorough comprehension of the contemporary environments of Verlorenvlei is considered to be an essential prerequisite if the anticipated permutations in the past vegetation and palaeoenvironments of this Sandveld region are to be recognised and understood. From the brief synopsis outlined in this chapter, it will have become apparent that the Sandveld environments demonstrate considerable geographic and climatic variability, with concomitant levels of floristic variability reflected in the diverse vegetation. The Verlorenvlei study region is not only juxtapositioned along a major phytochorological boundary but is also influenced by the dynamic interactions that originate along the marine-terrestrial interface. To adequately convey a critical appreciation of this complex biogeophysical interface is difficult, if not impossible, in this brief allotment. Be this as it may, it should be recognised that Verlorenvlei, with its transitional vegetation and its fluctuating estuarine status, is considered to represent an ideal laboratory in which to conduct investigations into the palaeoenvironmental history of the Sandveld. If indeed the climatic fluctuations, assumed for the terminal Pleistocene and Holocene, had any effect in determining the composition and distribution of former vegetation communities, then these fluctuations in vegetation are most likely to be manifested in the fossil pollen record of ecotonal environments such as Verlorenvlei.

Chapter 4

METHODOLOGY: QUATERNARY PALAEOECOLOGY

4.1 Introduction to Quaternary palaeoecology

Quaternary palaeoecology concerns itself with the reconstruction and interpretation of environments that existed during the last two million years of earth history. Since these environments no longer exist in their original form today, palaeoenvironmental reconstructions obligate the use of so-called 'key' fossils to provide the scientific clues necessary to 'unravel' and interpret the biogeographical history of such former environments. Many different types of fossil indicators are present for the Quaternary, these include; molluscs, arthropods, vertebrates, foraminifers, algae, bryophytes and vascular plants (refer to Berglund (1986) for a comprehensive review of respective analytical techniques). Of these Quaternary relics, the pollen grains of vascular plants are by far the most abundant fossils preserved within terrestrial sediments and their importance as palaeoenvironmental indicators remains unparalleled in Quaternary science. Indeed, such considerable emphasis has come to be placed on the analyses of fossil pollen that some researchers consider the technique to be synonymous with Quaternary palaeoecology itself (Cushing and Wright, 1967).

The principal technique in support of this study concerns itself with the analysis and interpretation of pollen produced by vegetation (both modern and archaic) of the Sandveld region. Pollen studies, in general, support a diverse range of applications including: descriptive taxonomy, genetic and evolutionary studies, archaeology, allergen research and even forensic science (Moore *et al.*, 1991). However, the best established pollen analytical technique, and arguably the most important, is that which concerns itself with the reconstruction of former vegetation communities and, by inference, past ecosystems, past environments and past climates. Put simply, the pollen from flowering plants may, under certain conditions, become preserved within organic deposits. As the deposits accumulate naturally, over time, a representative spectrum of pollen, from the surrounding vegetation, continues to collect and fossilise in the organic sequence. Many pollen grains exhibit a distinctive morphology which allows them to be identified and associated with the specific vegetation taxon that once produced them. A series of pollen samples, extracted from different depths within a stratified deposit, will reveal the nature and composition of vegetation at that location, at different periods of geological time. Sequential alterations among the frequency and composition of the vegetation

taxa, may therefore be interpreted to reflect changes within the environment. Much has been written about pollen analysis since its inaugural scientific application in 1916 by Swedish geologist Lennart von Post (Fægri *et al.*, 1989). Today it is widely recognised as one of the foremost (quantitative) techniques in Quaternary palaeoecology (Birks and Gordon, 1985).

4.1.1 Concepts of pattern, process and scale in palaeoecology

Regardless of the type of fossil 'key' employed, the principal challenge facing the Quaternary palaeoecologist is to identify observable biotic patterns in time and space (eg, population and community changes, migration events, extinction episodes, etc) and then to interpret them on the basis of the underlying (causative) processes. Central to this logic is the understanding that palaeoecological data reveal only the former patterns and never the actual processes that assembled them. Past processes (the causes) are linked to past patterns (the effects) only via analogy with contemporary environments in which modern patterns (of similar scale and nature to those identified in the past) are the result of observable processes operating in the present day (refer to Birks (1986) and Prentice (1988) for further discussion on the topic). This intrinsic philosophical equation is theoretically simple yet far more complex when applied in practice. For example, how does the palaeoecologist distinguish between those former patterns that are truly a product of processes brought about by physical changes in the environment (eg, allogenic succession) and those patterns that result from spontaneous biological processes acting in a constant environment (eg, autogenic succession)? Colinvaux (1983) suggests that this type of uncertainty may be resolved by referring to multiple, usually proxy, sources of environmental or ecological information (eg, sedimentology, rates of accumulation, geochemistry, alternative fossil data, etc), provided they remain independent of the primary evidence under consideration. Thus, if former patterns are to be interpreted realistically, individual sources of palaeodata should never be viewed in isolation, but rather as an integral component of the total former biostratigraphy. This form of integrative reasoning has been adopted throughout the investigation and interpretation of Sandveld palaeoecology.

Patterns of ecological (or palaeoecological) complexity operate at different scales in space and time (Woodmansee, 1988). The resolution at which these two variables are considered depends entirely on the nature of the investigation and the objectives thereof. Delcourt *et al.* (1983), advise however, that spatial and temporal scales ought to be considered together, for in many instances there exists a critical relationship

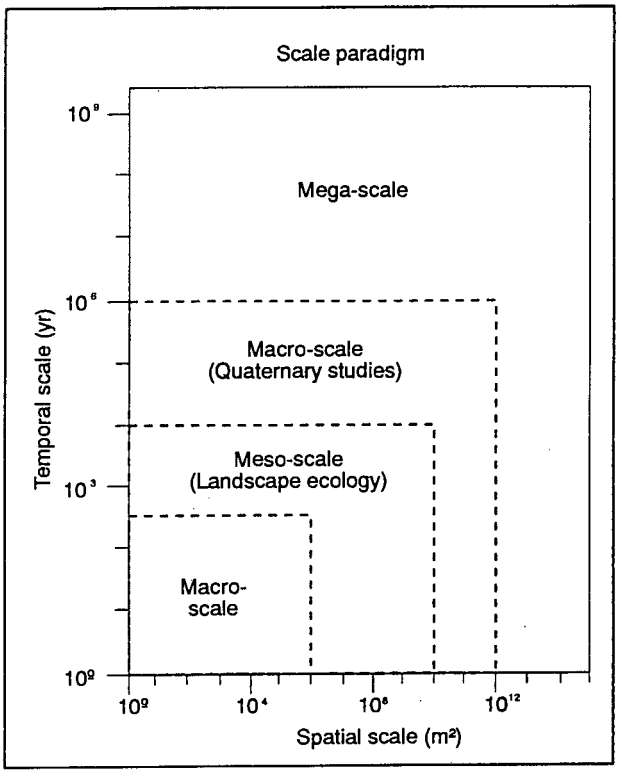


Figure 4.1 Spatial-temporal domains for a hierarchical characterization of environmental forcing functions; biological response and vegetational patterns. After Delcourt and Delcourt (1991).

between them. For example, in attempting to discern patterns of change within a regional landscape (10^4 - 10^6 km^2), such patterns may only be detectable over considerable periods of geological time, usually in the order of 10^4 - 10^6 years. In contrast, fine resolution patterns of change within a small closed-basin study site (10^2 - 10^3 m^2) may be detectable over periods of ecological time such as 10^1 - 10^2 years. For the most part, spatial and temporal hierarchies in Quaternary palaeoecology range between the meso and macro-scales (Figure 4.1), with domains of 10^3 - 10^6 years and 10^1 - 10^6 km^2 respectively (Birks, 1986).

With respect to the Sandveld and Verlorenvlei, the majority of the palaeoecological investigations presented in this thesis conform neatly to the meso-scale spatial-temporal domain, encompassing events of the Holocene (the last 10 000 years) and operating within a single watershed in the order of 1.89×10^9 m^2 or 1 890 km^2. Delcourt and Delcourt (1991) list the environmental forcing agents (processes) most likely to be operative at this meso-scale to be: climatic changes, alterations of disturbance regimes, changes in environmental gradients, and human cultural modification of the landscape. Corresponding biotic responses are given as changes in community composition across ecotones, and the establishment of new species and communities in response to glacial retreat (in the case of the Sandveld, marine regressions/transgressions are considered to

be an applicable surrogate). Patterns deemed resolvable at this scale include changes among vegetation types and changes in landscape heterogeneity. At this point it is instructive to note the following recommendation by Delcourt and Delcourt (1991): 'Techniques appropriate for study (of the meso-scale temporal domain) are primarily fossil evidence from pollen and plant-macrofossil records from lakes and other wetlands in humid regions, packrat middens such as in the arid western United States, and small mammals analyzed from cave and stream terrace deposits. The archaeological record also provides a wealth of data concerning changes in human populations and settlement patterns' (p 19).

Two exceptions to the general trend of meso-scale investigations should be noted for the palaeoecology of the Sandveld. The first involves a macro-scale attempt to elucidate the regional vegetation history based on the pollen from archaeological deposits from Elands Bay Cave dating to *circa* 40 000 BP. However, as will be shown in subsequent chapters, this study remains statistically problematic and warrants no further consideration here. The second study takes the form of a highly resolved palynological investigation of the lacustrine-riverine sediments deposited during the historical-colonial period (*circa* AD 1650 onwards) at Grootdrift (Baxter and Davies, 1994). This latter study, operating within true successional time (400 years) at the scale of 5×10^5 m^2 (or 50 ha), attempts to bridge the gap between meso and micro-scale spatial-temporal domains and, in so doing, links the realms of neoecology and palaeoecology. In the case of Grootdrift GDV4, the palaeoecological approach has allowed for a unique perspective to be drawn between the preconceived and the actual driving mechanism behind an observed hydrosere succession. This temporal-historical approach reveals a sequence of vegetation patterns brought about by an allogenic disturbance regime, in this case, anthropogenic forcing. Such insights are rarely visible to the neoecologist operating within the tight confines of the micro-scale.

Fundamental to all the historical sciences, and particularly to the form of palaeoecological reasoning alluded to above, is the principle of uniformitarianism, first philosophised by Lyell (1830). As will become apparent throughout this thesis, the reconstruction of past communities, ecosystems and environments (and almost all of the interpretations made in respect of Quaternary pollen analytical data) is based entirely on the contemporary ecological relationships exhibited by modern vegetation and the contemporary processes which govern its distribution. This assumption has been made in accordance with Lyell's principle of uniformitarianism which holds that all biological, physical and chemical processes that operate today are the same processes that have acted throughout geological time. In other words, modern environments and modern

processes can, by analogy, be consulted in order to interpret the nature of past environments and past processes (refer to Gould (1965; 1977) for further discussion on this topic). There are certain problems with uniformitarian assumptions (Gifford, 1981), and caution should be exercised when attempting to extrapolate ecological relationships beyond the dominion of evolutionary time. For example, the evolutionary development of pollen (eg, changes in structural morphology), as well as the ecological evolution of various plant taxa (eg, changes in environmental significance) are anticipated at the macro-scale ($5 \times 10^4 - 10^6$ years) and expected at the mega-scale ($> 10^6$ years). Furthermore, since palaeoecological and palaeoenvironmental interpretations, based on fossil pollen analyses, are critically reliant on the contemporary ecological relationships exhibited by modern vegetation analogues, it seems implicit that both accurate identification of fossil pollen and reliable palaeoecological interpretation, will decline in the face of longterm evolutionary change ($> 10^5$ years). For this reason (and others cited in Chapter 2), palaeoecological studies which require consideration of complex ecological interactions of modern biota to interpret the fossil record, should be regarded as being more reliable for the late Quaternary (say 40 000 BP to the present day) than for older Pleistocene and Tertiary periods. Despite this, the concept and principle of uniformitarianism remains central to the discipline of Quaternary palaeoecology and will be a recurrent theme throughout the interpretation of the Sandveld pollen spectra.

4.2 Principles of pollen analysis

A detailed account of the historical development of Quaternary pollen analysis is considered to be beyond the scope of this thesis (refer to Fægri *et al.* (1989) for an interesting and comprehensive review). However, it is worth mentioning that, for the most part, conceptual and methodological advances in the technique have, until fairly recently, been influenced by the temperate climates and lush vegetation prevalent in northwest Europe and North America. It is not surprising that the pioneers recognised the potential for the technique in these environments. The northern temperate latitudes provide an almost ideal environment in which pollen production by natural vegetation is consistently high. Abundant depositional environments, such as peat bogs, offer excellent opportunities for preservation, and the consistently low accumulation of clastic sediments results in enhanced pollen concentrations and ease of fossil pollen extraction. Given the development of pollen analysis in these temperate regions, a wealth of studies has emanated over the years. Indeed, the spatial distribution of fossil pollen studies in parts of Europe and North America is so well resolved that quantitative data is able to be

mapped spatially. In this way, synchronous lines of equal pollen frequency (isopolls), and various statistical derivatives (isophytes and isochrones), can be mapped across continental space and geological time, thus illustrating the former migration strategies of selected vegetation components (eg, Birks, 1985; Birks, 1986; Delcourt and Delcourt, 1991). In stark contrast to the proliferation and detail of pollen studies emerging from the Europe and North America, the sub-tropics, especially the semi-arid and arid environments which prevail at these latitudes, are strikingly depauperate. Horowitz (1992) proposes a number of reasons for this situation. Among these, the poor representation of proximal research institutions and the vast conceptual and practical barriers imposed upon 'traditional' techniques by the harsh environments of arid lands, are considered to be the most significant. The Quaternary palynology of arid regions, including the Sandveld, has thus remained poorly defined and largely unresolved. Elsewhere in the temperate and tropical regions, substantial advances in the concept, design and implementation of pollen analytical techniques continue to reveal new and dynamic insights into the vegetation history of these areas. Despite the obvious need for a distinctive research design and alternative methodological approaches to the palynology of arid lands, there are a number of common principles which govern all pollen studies, regardless of their biogeographical or chronological affinity.

The basic theoretical principles that govern Quaternary pollen analysis are well documented in most textbooks on the subject (Erdtman, 1943; Fœgri and Iversen, 1975; Moore and Webb, 1978; Birks and Birks, 1980; Fœgri *et al.*, 1989; Moore *et al.*, 1991) For ease of reference, Birks and Gordon (1985) provide an elegant 8-point synthesis which is summarised below.

1. Pollen analysis relies on the fact that all flowering plants produce pollen in great abundance (in a similar manner, pteridophytes, bryophytes, algae and fungi produce spores). Few of these pollen grains and spores achieve their natural function of fertilisation and most, owing to their small size (10 - 100 microns), are dispersed by wind and water.

2. Atmospheric turbulence and hydrological dynamics serve to mix the pollen into an almost uniform, area-defined 'pollen rain' which ultimately settles to the ground.

3. Under certain non-oxidising conditions the natural processes of decay and decomposition are inhibited and the outer pollen casings, composed of resistant sporopollenin, are preserved among accumulating organic sediments. Acidic, permanently water-logged, anaerobic environments such as peat bogs and vleis offer the most suitable preservation conditions.

4. Morphological variation between pollen grains allows for the taxonomic identification (usually to the family level) of the parent vegetation. In certain parts of the northern hemisphere the taxonomy of pollen grains and spores is well resolved (to genus and even to species level) and here, the existence of comprehensive pollen 'keys' assists greatly in the identification procedure (eg, Moore *et al.*, 1991);

5. The composition of the pollen preserved within the sediments reflects the composition of the atmospheric pollen rain which in turn reflects the vegetation constituents that formerly produced it. The fossil pollen therefore provide a signature of the former local and regional vegetation at that point in space and time.

6. It follows that, if a quantity of preserved pollen of known age is identified and counted into its constituent taxa, then the resultant pollen spectrum is an index of the vegetation surrounding the site of deposition at the time that the sediments and contained pollen were deposited. Under suitable conditions of preservation pollen concentrations can reach levels in excess of 10^5 grains cm^{-3} of deposit, requiring only small samples (usually less than 1 g) to secure an adequate sample population. This illustrates one of the most practical advantages of pollen analysis over other kinds of fossil studies, especially those in which individual fossils (eg, seeds or molluscs) are large and the size of the sediment sample is a limiting factor.

7. If preserved pollen samples are derived from several levels within an organic deposit (thus producing a stratified pollen assemblage), their respective analyses should reveal a punctuated sequence of progressive vegetation development at that location through the time period represented by the sedimentary record.

8. If a set of stratified pollen assemblages are analysed from several different locations, it becomes possible to compare the sequential development of vegetation through time and space.

All fossil pollen investigations adopt a common, stepwise procedure of interpretative analysis. Given a hypothetical research question and assuming that pollen is present (either in stratigraphic or spatially distributed form), the first step is to identify individual plant taxa on the basis of their recognisable pollen signatures. In this way, the analyst will be able to reconstruct the composition and distribution, in time (stratigraphically) and in space (geographically), of the individual vegetation components. Since we are dealing with quantitative data, the procedure can be taken a step further by reconstructing the abundance of individual components in time and space and consequently the dynamics of plant populations. The next step is to reconstruct the former vegetation

community on the basis of the composition and distribution of entire plant assemblages in time and space. Once this step has been satisfied and, given the understanding that alterations within the composition of natural vegetation are indicative of changes within the environment (Birks and Birks, 1980) it becomes possible to interpret the sequence of environmental changes through time. With sound knowledge of the ecological requirements and tolerances of both the individual components and various plant assemblages, reconstructions of the vegetation and, interpretations regarding the palaeogeography of the former environment, can be made. Ultimately, the very biotic and abiotic processes that produced and controlled the observed palaeoecosystem may themselves be inferred.

The basic principles of pollen analysis provide a common theme which guides all fossil pollen studies. However, the list of principles recorded above is neither conclusive nor inflexible. Variation, particularly with respect to levels of taxonomic resolution and pollen concentration do exist - and to a large extent the authenticity of these casual assumptions are themselves open to interpretation. In this respect, it is necessary to consider briefly the potential limitations of pollen analysis, particularly those universal methodological and statistical problems concerning pollen production, pollen dispersal and pollen preservation.

4.2.1 Problems associated with pollen analysis

Considering the long and convoluted series of events that influence the journey of the pollen grain from the anther to the final pollen diagram, the potential for distortion can be considerable (Figure 4.2). In their textbooks on pollen analysis, Birks and Birks (1980) and Fægri *et al.* (1989) provide comprehensive reviews of those processes and phenomena that constitute problems and limitations for pollen analysis. Many of these problems are associated with naturally occurring differentials in pollen production, pollen dispersal and pollen preservation. Although the magnitude and specific nature of these limitations may vary from taxon to taxon, from one geographical location to another, and at different points in time (eg, diurnal and seasonal variations), their physical extent is certainly universal. In an effort to model some of these disparities, a plethora of studies (confined mostly to parts of Europe and North America) have attempted to quantify volumes of pollen production and to resolve the mechanics of dispersal for individual plant taxa (Moore *et al.*, 1991). However, for most parts of the world such models do not yet exist and individual researchers are obliged to identify, document and, where necessary, compensate for perceived distortions in an effort to secure the best possible final representation.

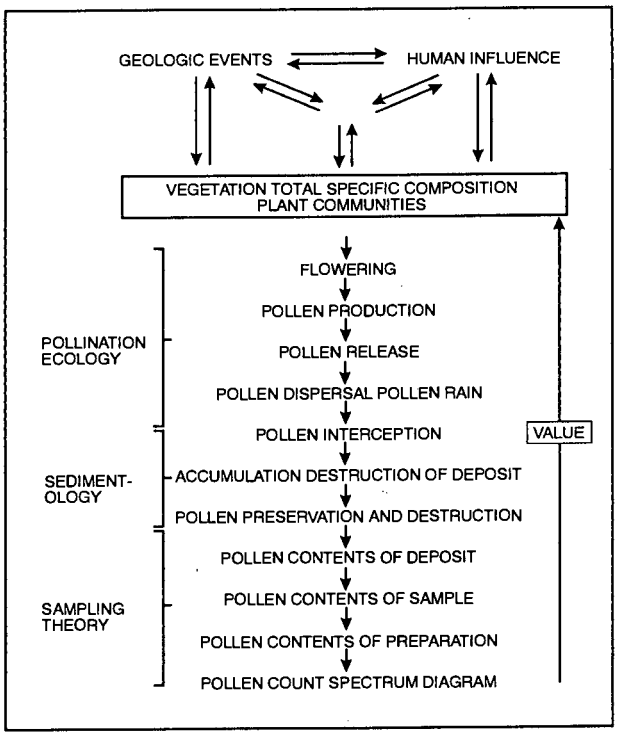


Figure 4.2 Flowchart of pollen analysis.

4.2.1.1 *Disparities in pollen production and pollen dispersal*

In order to illustrate some of the complexities of pollen production and pollen dispersal, consideration is herein given, by way of examples, to differences in pollination strategies. Studies in pollination biology identify a number of different pollination strategies which contribute differentially to the collective pollen rain. In essence, there appears to be a correlation between the mode of dispersal and the volume of pollen production. Inefficient fertilisation strategies such as wind pollination (anemophily), require enormous quantities of pollen to be liberated freely into the atmosphere. As a consequence of this 'hit and miss' approach to fertilisation, only a negligible amount of pollen satisfies its original function while the vast remainder contributes significantly to the overall pollen rain. By comparison, specialised forms of pollen dispersal such as that of zoophilous plants - which depend on a variety of animals as the transporting medium - produce comparatively fewer pollen grains and are expected to be less well represented among the overall pollen rain. For example, Orchidaceae pollen is not liberated at all, but is retained in the pollen sac which is collected, intact, by specialised insects.

Representative bias of this nature has come to be anticipated for the pollen data of the Sandveld where a significant proportion (some 88 %) of the fynbos, Strandveld and karroid parent vegetation has evolved to become entomophilous (Steiner, 1987; Bond and Goldblatt, 1984). Consequently, anemophilous pollen producers such as the omnipresent Poaceae and Restionaceae and various local vlei elements such as *Typha* and Cyperaceae, are considered to be relatively over-represented in the pollen spectra. Despite the potential of these abundant anemophilous components to 'swamp' the pollen signal from the predominantly entomophilous fynbos and Strandveld communities, taxonomic diversity does not appear to be compromised in the pollen spectra from the Sandveld. Two possible explanations may account for this anomaly. For example, Asteraceae, Anacardiaceae, Fabaceae and even Scrophulariaceae pollen is surprisingly well represented in the Sandveld deposits, suggesting that certain contributors to these predominantly entomophilous families may be engaged in a from of 'facultative anemophily' - producing large quantities of pollen despite adopting an insect-pollination strategy (eg, Williams, 1972). Furthermore, the majority of the entomophilous Sandveld taxa are pollinated by bees and flies (Whitehead, 1984; Rebelo, 1987) and it is possible that excessive pollen loads may become dislodged during flight and dispersed as if wind-pollinated. This aberration has long been observed by mellisopalynologists who refer to the process as 'buzz pollination' (Buchman *et al.*, 1985, after Fœgri *et al.*, 1989). At this point it should be stressed that the complexities of pollen production and dispersal are not confined solely to the mechanics of pollination, but rather depend on a myriad of ecological, biogeographical and climatic factors (eg, Janssen, 1966; Tauber, 1967; Birks and Birks, 1980; Jacobson and Bradshaw, 1981).

4.2.1.2 *Disparities in pollen preservation*

The other major area in which pollen analysis is open to interpretation is the problem of differential pollen preservation. This phenomenon is based primarily on inherent morphological and chemical differences between pollen types, ultimately favouring the preservation of one type over another (Havinga, 1964; 1984). Horowitz (1992) identifies four principal stages of natural pollen destruction (the reciprocal of preservation), beginning with those palynomorphs that oxidise almost immediately following their release from the anther. This pollen never forms part of the pollen spectra and is consequently of no use to the pollen analyst. Two intermediate stages of deterioration are attributed to the mode and duration of the transport medium (eg, wind, water, animals) while the fourth stage concerns the differential destruction processes that follow deposition and diagenesis. This latter stage is probably the most influential in terms of

differential pollen destruction and has the most bearing on the fossil pollen spectra, yet the processes at work here are complex and poorly understood. Besides the obvious chemical and mechanical processes such as oxidation and compaction, physical parameters such as pH, temperature and humidity play a significant role in pollen deterioration (Cushing, 1967; Havinga, 1967; Birks and Birks, 1980). Other factors contributing to the differential degradation of pollen include the activity of microbial bacteria (Elsik, 1966), and various post-depositional activities such as chemical carbonisation (Horowitz, 1992) and fire (personal observation).

Depositional environments in drylands are notoriously poor preservers of pollen, seldom, if ever, conforming to the 'ideal' peat-based deposits which epitomise palaeoecological research in northwest Europe and North America. By 'traditional' standards of pollen analysis, most dryland deposits would be considered inappropriate for investigation since they are routinely subject to conditions which are detrimental to preservation. With the exception of the riverine-lacustrine sediments, most terrigenous late Quaternary deposits identified from the Sandveld are, predictably, impoverished in terms of their frequency and diversity of pollen. For example, the archaeological record from Spring Cave and Elands Bay Cave reveals the macrophytic remains of *Zostera* (a probable bedding material and hence significant cultural indicator) in parts of the stratigraphic sequence (R Yates, personal communication). Surprisingly, no reliable identifications of this taxon could be determined from the profile, even from the same stratigraphy as the macrophytic remains. Despite *Zostera* adopting a sub-aquatic pollination strategy (hyp-hydrogamy), such pollen is generally abundant among modern plant material and its presence in the fossil sequence might ordinarily be expected. However, the nature of hyp-hydrogamous pollen grains is such that they exhibit an extremely delicate exine (Fægri *et al.*, 1989), the structure of which is unlikely to survive the complex diagenic processes inherent in cave deposits. An additional factor contributing to differential pollen preservation/destruction is the proximity of fire to the depositional environment. Fire is known to have been an inextricable component of late Quaternary vegetation evolution in the southwestern Cape (Hendey, 1983; Meadows and Sugden, 1991a,b) and evidence is readily available in most sedimentary deposits. Hearths are well documented in archaeological sites of the Sandveld (Parkington, 1986) and the abundance of ash and charcoal in these circumstances is often accompanied by a general decline in both pollen frequency and diversity. This phenomenon is particularly evident in the Elands Bay Cave deposit where a marked increase in charcoal is accompanied by a radical decline in pollen frequency and diversity - the notable exception being echinate Asteraceae (and to a lesser extent Chenopodiaceae) palynomorphs. A similar occurrence, indicating the persistence of Asteraceae pollen in

fire-sintered deposits, is recorded from an archaeological cave site on Table Mountain (Baxter, 1989). It is unlikely that the exclusive presence of Asteraceae pollen in these sintered deposits is a function solely of post-fire succession among Asteraceous shrubs, as this is not supported by established theory on fynbos ecology. A more likely interpretation is that, despite the deleterious impact that fire has on general pollen preservation, certain pollen taxa such as Asteraceae and Chenopodiaceae appear to demonstrate an enhanced resilience to deterioration by oxidation and fire.

Problems of representivity such as those imposed by natural differentials in pollen production, dispersal and preservation are by no means the only problems that the pollen analyst can expect to encounter during an investigation. A distinction can be made with regard to those fundamental ecological problems inherited from a distant event in the geological past (and which are entirely beyond the control of the analyst) and a second set of potential methodological limitations associated with the actual palaeoecological investigation. Perhaps more challenging to the intuition and skills of the analyst, these latter problems arise from procedural complications encountered during the sequence of analysis beginning with sampling and ending with interpretation. Typically, these problems arise during sample preparation, pollen identification, statistical treatment and chronological interpretation. For example, the absence of *Juncus* pollen from the surface spectrum at Grootdrift is considered surprising given its contemporary distribution among the riparian vegetation at the site. However, following consideration of the chemical technique used in preparation of the samples, it was discovered that the application of acetolysis may have discriminated adversely against the delicate Juncaceae palynomorphs (eg, van Zinderen Bakker, 1957; Godwin, 1977). This hypothesis was later confirmed by the presence of *Juncus* in samples from the same sequence, prepared by an alternative method using mineral separation. To a large extent, these types of methodological problems may be considered site and survey specific, and their magnitude and bearing on the final outcome of the study is dependent on the nature of the research question and the aptitude of the analyst. For the purpose of this thesis, those methodological complications encountered during the course of the investigation are advertised, where appropriate, in subsequent chapters.

4.2.2 Contemporary pollen analysis

The potential for problems among the basic principles of fossil pollen analysis, as discussed above, has centred on the natural differentials that occur in pollen production, dispersal and preservation. To some extent, such problems of representivity in palaeoecology can be compensated for through an improved understanding of

modern vegetation-pollen relationships and recent pollen spectra (Birks and Gordon, 1985). One of the most critical assumptions underpinning Quaternary pollen analyses is the premise that fossil pollen spectra serve as an index of former pollen rain and, therefore, former vegetation communities. Having considered the potential of natural variability in pollen dynamics, it is clear that the precise relationship between plant taxa and pollen rain is indeed a complex one. Davis and Goodlett (1960), Janssen (1966; 1967) and Webb (1974), among others, were the first to recognize that a revision of contemporary pollen rain dynamics would not only allow for an informative evaluation of fossil pollen spectra, but would also aid in the final vegetation history reconstruction. The foremost advantage of characterising modern vegetation communities in terms of their contemporary pollen signatures, lies in the statistical comparisons (Birks and Gordon, 1985) that can be drawn between these so-called modern analogues (the parent material which is visually identifiable in the contemporary landscape) and the fossil pollen record (for which we are unable to visualise the actual parent vegetation). In certain parts of the world, the ever-improving taxonomic resolution of modern pollen types, combined with abundant fossil pollen data, has allowed for the determination of groups of fossil types based on similar patterns of distribution in time and space (Janssen and Birks, 1994). In such cases, patterns among dominant types have proved to be as indicative of stratigraphy (and environmental fluctuations) as the rarer individual pollen types. Within the Sandveld, environmental conditions are expected to act against the preservation of rare types. A statistical approach in which equivalence is sought between groups of modern 'analogue' pollen and groups of fossil pollen is thus considered to be an important step in the reconstruction of the vegetation history of the Sandveld region.

Despite the obvious importance of contemporary pollen-vegetation studies in Quaternary palynology, it is paradoxical that this important interpretative strategy is often neglected in those areas where fossil pollen spectra are especially complex and difficult to define - such as the drier parts of the world, traditionally perceived to be of only marginal palynological importance. For southern Africa, the enormous biogeographical and climatic variability, together with the sheer size of the region, have given rise to fossil pollen studies that are widely distributed (spatially and ecologically) and frequently isolated (Sugden, 1989). In turn, this state of affairs has undoubtedly played a contributory role in the paucity of contemporary pollen studies for the subcontinent. In southern Africa, studies incorporating contemporary vegetation-pollen relationships include the pioneering work of Coetzee and van Zinderen Bakker (1952) in the former Orange Free State, Scott (1982) in the former Transvaal, Meadows (1984) on

the Nyika plateau in Malawi, Sugden (1989) on the Cederberg escarpment in the southwestern Cape Province and Cooremans (1989) in central southern Africa.

In an effort to secure the most meaningful historical vegetation reconstruction for the Sandveld, two facets of contemporary pollen-vegetation relationships have come under scrutiny. In the first instance, an attempt has been made to establish the relationship between recent vegetation and the ensuing pollen signature, by virtue of sampling the surface sediments from a wide range of Sandveld environments. These data will ultimately be used to aid in the interpretation of the fossil pollen spectra and will provide a set of modern analogues against which the palaeodata can be statistically compared. Secondly, modern pollen has been collected from known taxa in the Sandveld, as part of a reference collection, to assist in the identification and taxonomic resolution of fossil pollen from the region. The methodologies of these techniques are explored in more detail in subsequent chapters.

4.2.3 Fossil pollen analysis of arid lands

In the preface to his monograph on the palynology of arid lands, Horowitz (1992) cites the intention of the book to be, among others, '...for students and scientists who wish to broaden their knowledge beyond 'classical' palynology...'. The distinction between classical palynology and arid lands' palynology is vigorously reinforced throughout the text and lends credence to Horowitz's intimation that, by refusing to accept the limitations posed by arid lands' palynology, scientists were contributing towards a new ramification in (palaeoecological) science. In essence, the distinction between the disciplines can be attributed to conceptual and methodological differences, rather than a fundamental change in philosophy. A suitable analogy can be drawn between two mechanics, one working on a petrol engine, the other on a diesel version. Whilst each mechanic may develop different skills and techniques, they both use similar tools and they are both striving, ultimately, towards the reconstruction of an internal combustion engine. In a similar vein, palynological investigations of arid lands require a certain modification of traditional attitudes and some re-engineering of the basic principles in order to overcome those limitations imposed by hostile environments. This section aims to demonstrate, briefly, some of the obstacles encountered by palynologists working in arid environments. Where appropriate, site-specific examples from the Sandveld are used to illustrate the point.

Generally speaking, the scarcity of suitable pollen-bearing sites in arid environments invariably leads to the analyses of the available rather than the desirable sequences. An interesting example, which illustrates both the determination and resourcefulness of arid lands' palynologists, is to be found in the palynology of coprolites. In southern Africa, one such source of faecal pollen is that which is preserved within the hyracium deposits produced by rock hyraxes (*Procavia capensis*) - rabbit-sized herbivores known locally as 'dassies'. In essence, hyracium is a consolidation of faecal pellets welded together by concentrated urine (Smithers, 1983). These deposits act as an ideal repository for both ingested and atmospheric pollen and, under certain conditions, accumulate to form stratified sequences (Scott and Bousman, 1990). Dassies are widely distributed throughout the Sandveld but are particularly prevalent among the sandstone koppies in the vicinity of Verlorenvlei. Encouraged by the work of Scott (1987; 1990; 1994), an investigation into the suitability of Sandveld hyracium deposits, for pollen analysis, was conducted by the author. Despite a thorough survey, all the hyracium deposits encountered in the region proved to be dry and cohesionless, and appeared to lack the texture, consistency and distinct stratification of dassie-middens described from elsewhere in southern Africa (eg, Scott and Bousman, 1990; Scott and Vogel, 1992).

The Sandveld, with its extensive cover of unconsolidated surficial sediments and its predominant aeolian regime (Harmse, 1988), is naturally predisposed to the impacts of erosion, deposition and the constant reworking of sediments. Verlorenvlei is one of a few depositional sites in which pollen is known to be preserved in the region. Even so, the combination of sparse vegetation cover and the rapid sedimentation (and erosion) rates - typical trademarks of dryland estuarine environments, such as Verlorenvlei - have resulted in poor levels of pollen concentration. In turn, this has contributed to a plethora of technical complications in the laboratory where large sediment samples (eg, 10 - 100 g - or two orders of magnitude larger than those typically required from temperate peat sites) have proved cumbersome and time consuming to process. Satisfactory results in the laboratory are further constrained by the high clastic content of the parent material and the sensitivity of many palynomorphs to the vigours of chemical oxidation and acid digestion. Where pollen concentrations are routinely low, conceptual problems arise with respect to the statistical significance of such samples (Fægri *et al.*, 1989). However, Horowitz (1992) argues that such problems of representivity should not necessarily constrain the interpretation of pollen analysis from arid environments. Some of the ways in which improved statistical meaning can be attached to poor pollen counts is by the grouping of taxa into ecological provenances (eg, Scott, 1982) or by the combination of counts from adjacent pollen spectra (eg, Horowitz and Horowitz, 1985).

One of the critical tasks facing the arid lands' palynologist is the need to distinguish between those pollen taxa that are produced and dispersed locally (eg, wetland elements produced in close proximity to the site (± 20 m), usually in great abundance) and those pollen taxa that are regional or extralocal in their origin and distribution (Janssen, 1967). This is particularly important when attempting to interpret the palaeoecology of arid lands where regional vegetation provide a more reliable overall index of the state of the environment than localised hydrophil elements. However, in certain Verlorenvlei sites, such as Grootdrift and Klaarfontein, the pollen of local taxa tend to dominate the spectra to the point of masking (statistically concealing) the regional pollen signal. To some extent, the potential loss of palaeo-interpretive clarity may be overcome by ignoring the aquatic and riparian elements (eg, Cyperaceae and *Typha*) and selectively counting the critical terrestrial indicators (eg, *Podocarpus*, Proteaceae, Restionaceae, etc). However, the problem is further compounded by the presence of cosmopolitan veld elements (eg, Poaceae, Asteraceae, Hyacinthaceae, etc) which are ubiquitous throughout the Sandveld. Poaceae, for example, contribute to the overall pollen rain both as localised vlei elements (eg, *Phragmites*) and regional terrestrial grasses (eg, *Eragrostis, Erharta* and *Cynodon*). Obstacles such as these pose difficult challenges for palynologists in general, but are of even greater consequence in arid environments.

In stark contrast to temperate regions of the world, where traditional palynology has become dependent on a select group of 'indicator-type' arboreal pollen for the primary source of (palaeo) environmental information (eg, Birks, 1989; Gear and Huntley, 1991), arid environments are notable by the absence of trees and the dominance of non-arboreal pollen types (Horowitz, 1992). This phenomenon is particularly evident in the southwestern Cape Province of South Africa, where the natural fynbos vegetation is characterised by an enormous diversity of sclerophyll shrubs, heaths and annuals, but very few trees (Cowling, 1992). The consequent utilisation of 'surrogate' non-arboreal pollen types, as opposed to arboreal pollen, highlights one of the main differences between the palynology of richly vegetated and dryland areas. For the most part, genera and even species of arboreal pollen from temperate regions are readily identifiable. On the other hand, pollen from non-arboreal communities are seldom identifiable beyond the family level. This identification problem is further compounded in arid environments, firstly, by the comparatively poor state of preservation of fossil pollen and, secondly, by the absence of adequate reference material from which to resolve the identification of fossil palynomorphs. As such, it is generally accepted that the conceptual and methodological problems attached to arid lands' palynology may impose a limiting factor to the degree of accuracy that can be assigned to the results

(Horowitz, 1992). Such complications highlight the need for improved levels of taxonomic resolution and a thorough understanding of contemporary vegetation-pollen relations in arid environments. Despite these obstacles, palynologists such as van Zinderen Bakker (1980; 1984; 1987) and Scott (1987; 1988) in southern Africa, Davis and Hall (1988) in the American southwest and Horowitz (1989; 1992) in the Near East and Israel, have made profound contributions to the palaeoecology of arid lands.

4.2.4 Fossil pollen analysis of archaeological deposits

Archaeological sites, indicative of both transient habitation as well as prolonged (or repeated) settlement by prehistoric people, are commonplace among the Sandveld environments. The cultural remains of indigenous people are especially apparent at Verlorenvlei which appears to have been a focal point in terms of human habitation, certainly since the Last Interglacial (Parkington, 1981; 1986). The attraction of the Verlorenvlei region to hunter-gatherers can be attributed to the wide range of life-sustaining natural resources that reach a confluence at Elands Bay. Here the rich upwelling sub-Antarctic bottom waters ensure an abundant supply of edible shellfish and other marine resources (Buchanan *et al.*, 1984), the coastal plains, at times, supported abundant large grazing fauna (Klein, 1984) and the Verlorenvlei wetlands are expected to have supplied a critical fresh water component as well as a range of consumable resources. These would have included fish, waterfowl and plant material - the latter ostensibly for bedding and weaving purposes (R Yates, personal communication). The various occupation sites scattered around Verlorenvlei assume a number of different forms, including: ephemeral open air sites (Manhire, *et al.*, 1984), small rock shelters such as Tortoise Cave (Robey, 1987) and deep cave sequences such as Diepkloof Cave (Parkington and Poggenpoel, 1987) and Elands Bay Cave (Parkington, 1981).

In terms of fossil pollen analysis, the open air sites have little to offer in the form of stratified organic sequences. Their presence in the landscape is marginal and generally confined to those low-lying areas among the dune fields and littoral sands where active deflation has exposed a scatter of stone tools and occasional bone remains (Lancaster, 1986). By virtue of their more sheltered disposition and enduring geology, the sandstone caves near Verlorenvlei, tend to act as sediment accumulators, collecting both natural debris in the form of roof spalls and aeolian dust, as well as cultural debris in the form of mineral, animal and vegetable matter. The introduction of this human cultural component, particularly elements such as edible plant matter, bedding and weaving material, wood and charcoal, have contributed to the formation of semi-organic

sequences which may be favourable for the preservation of pollen grains. In the case of semi-arid and arid environments, where organic preservation is generally constrained by the harsh environment, archaeological sites may present the best, if not only, opportunity to sample fossil pollen.

There are, however, a number of complications associated with palynology of archaeological sites - a sentiment echoed by van Zinderen Bakker (1982) who, in attempting to assess the palynology of Wonderwerk Cave, testified to the many difficulties of working in archaeological cave sites. Among the potential problems, the scarcity of pollen entering caves, the repeated disturbance of sediments and the selective introduction of plant material can all lead to interpretative difficulties. Even in the absence of human occupation, burrowing animals can disturb the stratigraphic integrity, while nesting birds and especially bees can introduce considerable bias to the pollen signature. Such is the case for Cecilia Cave on Table Mountain (Baxter, 1989), where the former Middle Stone Age site is presently occupied by a substantial bees' nest, contributing, possibly, to the large proportion of Asteraceae pollen found towards the top of the sequence.

Despite the potential for problems in the palynology of archaeological sites, careful analysis and shrewd interpretation can deliver significant results. For example, the fossil pollen results from Wonderwerk Cave (van Zinderen Bakker, 1982) compare favourably with the micro-and megafaunal assemblage studies from the same location, while Scott's (1987) analysis of pollen from hyena coprolites and sediments from Equus Cave in the southern Kalahari is an eloquent example of just how versatile the technique can be.

4.3 Techniques in geoarchaeology, geomorphology and sedimentology

The term *geoarchaeology* was first coined by KW Butzer to account for the need to give due emphasis to the interrelatedness of the physical environment and cultural systems when attempting to interpret prehistory (refer to Gladfelter (1981) for a review). Developing from this conception, geoarchaeology has come to be considered an essential ingredient in an ecological approach to prehistory - especially where the practitioner can contribute significant information regarding the availability or limitation of critical environmental resources, such as food and water (Butzer, 1977). Considering the rich archaeological heritage within the Verlorenvlei region of the Sandveld, human-cultural intervention and active participation within the environment is implicit (Miller, 1987). The extent to which natural environmental changes may have determined the

behaviour of these human populations by prompting cultural adaptation is intrinsically dependent on a knowledge of the former biogeophysical environments. By corollary, it is important also to consider that human interaction within a landscape (particularly following the introduction of pastoralism and agriculture) cannot reasonably be divorced from any palaeoecological interpretation of the regional environment. In this regard, there is much to be said for palaeoenvironmental interpretations that are based on formal training within the earth sciences and archaeology. This assertion is supported by the author who has drawn extensively on his background in archaeology and biogeography to aid in the elucidation of the environmental history and cultural prehistory of the Sandveld.

An appreciation of geomorphology, with its roots in geology and geography, provides a solid foundation for uniting the earth science and archaeological interests of geoarchaeology. Geomorphological studies in general have contributed significantly to the growing body of evidence that supports the interpretation of extreme environmental variability during the Quaternary Period (Thorn, 1982). Landscape features such as valleys, slopes, terraces, weathering products, soil development, pan deposits and dune fields provide a plethora information regarding the physical development of the environment in response to changes in climate and sea-level (Goudie, 1992). One of the most satisfactory methods of using geomorphic landforms to reconstruct dry phases of the Quaternary is the study of the extent of former dunefields by fossil forms. Grove (1969) and Lancaster (1981) have successfully demonstrated the importance of these relict landforms, as palaeoenvironmental indicators, within the African sub-continent. Despite the significance of the latter two studies, there is growing consensus that regional generalisations are, by implication, too imprecise to provide adequate reconstructions of past climates and geomorphic influences (Miller, 1987). Rather, multiple geomorphic studies within an area of limited jurisdiction are likely to produce results with an improved resolution. Among the Sandveld, studies concerning the activity of deflation hollows (Lancaster, 1986) and aeolian deposits (Harmse, 1988), the nature of sedimentary accumulations in archaeological sites (Butzer, 1979), and the implications of sea-level changes on landscape morphology (Miller, 1981) are a few examples of geomorphological studies that have contributed significantly to an understanding of the palaeoenvironmental evolution of the region. In his review on geoarchaeology at Verlorenvlei (Miller, 1987) identifies a number of key research areas that require further consideration. These include, among others, a thorough geographic assessment of the Verlorenvlei and Kruis River catchment, the citing of a series of boreholes to sample the sedimentary record preserved within the drowned palaeovalley and, more specifically, research aimed at a full description of the palynology, palaeontology, dating and

sedimentology of the Holocene sequence. In many respects, this study will attempt to address all of these criteria, and, despite the major emphasis being placed on palynology, the reconstruction of the Holocene palaeoenvironments has been substantially augmented by an assessment of the fluvial palaeohydrology and estuarine geomorphology of the Verlorenvlei system. Furthermore, careful evaluation of the contemporary regional geography has provided overwhelming support for the fossil and sedimentological evidence which suggests that landscape denudation has accelerated under the influence of overgrazing and centre-pivot irrigation.

4.4 Contemporary ecological perspectives from Verlorenvlei

In view of the widespread and frequently pervasive human disturbances that tend to occur within dryland aquatic environments such as Verlorenvlei, it is important to lend careful consideration to the appropriateness of conserving systems which are commonly perceived to be 'pristine', when in reality they have been substantially transformed by human interaction (Simmons, 1990). This statement does not mean to imply that only 'pristine' systems are worthy of conservation action. Indeed, the converse is true - the rarity of such environments dictates that the majority of them require urgent action, irrespective of their current ecological status. The point is simply that conservators must carefully ask the questions: what *is* the ecological status of the system, and what is it being conserved for - what are the conservation objectives? In this regard it is necessary to consider, in greater detail, the concept of 'pristine' since it is often fraught with ambiguity, and can be particularly misleading when used to describe ecosystems.

In the literal sense, a pristine environment invokes an image of a landscape devoid of any form of human impact. However, it is difficult to imagine that there can be many places on earth where during the course of prehistory, or more recently, humans have not left some form of lasting impression/impact. Furthermore, the notion of a pristine environment often inadvertently implies that such a landscape has remained naturally preserved through time. The image thus created is one of a static system, operating within fixed temporal, spatial and physical boundaries, unperturbed by forces of natural and anthropogenic change. However, it is widely accepted that ecosystems are dynamic, that they respond to episodes of natural climatic and environmental change and that they are governed by processes which dictate a course of natural succession. Since anthropogenic interactions cannot be divorced from the global equation, all scales of ecosystem are subject, in some form or another, and at some time or other, to human impacts. In ecological terms therefore, the definition of a 'pristine environment' is

seen to be both confusing and problematic. The important consideration therefore, is not so much the presence or absence of human interaction within the system, but rather the nature and magnitude of associated impacts. Clearly, the degree to which a system will respond to, and reflect such impacts, is dependent on its particular set of inherent tolerance thresholds. In preference to the terms 'pristine' and 'impacted', it is suggested that ecosystems be categorised into one of the following three states of ecological equilibrium (bearing in mind the underlying dynamism of all ecosystems):

1. **Natural.** Such systems are seen to be functioning normally, with limited anthropogenic interactions and few, if any, deleterious human impacts. Such ecosystems are dynamically self-sufficient, require no management intervention and should be allowed to follow their natural course of fluctuation and succession; for example, a high-altitude mountain stream, or a remote coastal lagoon.

2. **Transitional.** Human interactions with the system (either from within or outside) are approaching the tolerance thresholds, and the system is forced to compensate by either continually adjusting its equilibrium, or by moving to a new state. In order to maintain equilibrium, the system may have to be subjected to permanent management intervention, but this requires decisions regarding the desired condition and characteristics of the system; for example, a river servicing a nature reserve, but which is dependent on controlled releases of water from an upstream impoundment. In this case, one may chose to manage the system so that it reverts to a more 'natural' state, maintains its current condition by adjustment, or is allowed to find a new, altered level and is then managed at that level.

3. **Altered.** Pervasive and progressive human intervention exceeds the tolerance thresholds of such systems, resulting in widespread disturbance of many or of all ecological processes. Massive remedial action is required to re-establish these systems to the level of 'transitional' ecological equilibrium. A total reversal to the former state ('natural') is by now impossible; for example, a canalised urban river or a once mobile river mouth that has been stabilised by harbour development.

One of the specific objectives of this study will be an attempt to define the parameters by which Verlorenvlei, a wetland system with high conservation priority in a dryland environment, might be considered to be in one of the following states of ecological equilibrium: i) natural (or so-called 'pristine'), ii) transitional, or iii) altered. In so doing, the study will draw on palaeoecological information gained from a high resolution analysis of the palynology and fluvial geomorphology of the wetlands system.

Chapter 5

TECHNIQUES IN MECHANICAL SAMPLING

5.1 Introduction

Palaeoenvironmental investigations such as those undertaken in this study are typically dependent on sequences of samples derived from beneath the surface of unconsolidated and, where possible, minimally disturbed and highly organic sedimentary deposits. In the absence of suitable exposed sections, it becomes necessary to employ the use of appropriate sampling apparatus in order to generate a continuous range of vertically-aligned, depth-correlateable samples. The choice of sampling system is critically dependent on: i) The nature of the organogenic deposit and, ii) the specific requirements of the investigation. Given that many so-called 'undisturbed' sites are often those which are restricted in terms of their accessibility, the use of some sort of compact, portable, hand-held sampling device is often a prerequisite. A plethora of sampling devices of this nature exists and it remains for the investigator to select the most appropriate system. In the arid regions of southern Africa, for example, many deposits tend to be characterised by a coarse sandy matrix, whereas organic-rich 'peat' deposits, typical of northern temperate latitudes, are noticeably rare (Meadows, 1988a,b; Harwood, 1994). Under these circumstances, the application of popular hand-held samplers such as the side-filling Hiller and Russian models (Aaby and Digerfeldt, 1986) and the classic Piston sampler (Livingstone, 1955; Wright *et al.*, 1965) have proved to be largely ineffectual (Sugden, 1989). Better suited hand-held samplers for coarse particulate sandy sediments may be found in the form of gouge corers, or where sediments are dry and cohesionless, rotary soil augers (personal observation). Aijkelkamp, the Netherlands-based agricultural research equipment manufacturers, supplies a useful hand auger set for use in heterogeneous soils and sediments. The Aijkelkamp gouge auger, a crude, albeit versatile, end-filling derivative of the Russian sampler, together with an assortment of rotary auger attachments, have been used in support of this study. These instruments were employed mostly for the purposes of reconnaissance fieldwork, but, they failed to satisfy the primary sampling requirements. The gouge auger is constrained, in particular, by the limits of human endurance required to drive the sampler down into the substrate, especially in well-compacted, largely clastic sediments, such as those which occur throughout the Sandveld. Furthermore, the sampling technique is prone to distortion and contamination of core material and requires skillful application when sampling beyond a few metres (Sugden, 1989). Given the evident limitations of the

gouge auger, it was recognised early during the fieldwork component of this project that in order to satisfy the primary objective of securing long, continuous and minimally disturbed sediment cores from Verlorenvlei, a more dynamic, mechanically-powered technique would need to be applied.

5.2 Commercial drilling investigations

Large scale, commercial drilling operations, commonly associated with geotechnical exploration, mining or borehole drilling in arid areas, are considered a useful (if not opportune) means of obtaining sample material. Often, however, the procedures employed during large-scale drilling operations are such that the samples are too coarse or too unreliable for meaningful, high resolution palynological studies. Nonetheless, large scale drilling operations do provide a unique opportunity to conduct low resolution palynological investigations, often over considerable depths of deposit and by implication, over considerable periods of geological time (eg, Partridge *et al.*, 1993). A synopsis of previous drilling investigations, mostly geohydrological, conducted over the years in the Verlorenvlei region, is given in Jolly (1992) and Maclear (1994). The most noteworthy and potentially interesting geotechnical investigations commenced with the exploratory drilling of the estuarine channel in anticipation of the Sishen-Saldanha railway line in 1974, during which six boreholes were drilled to an approximate depth of 30 m (Miller, 1982). From this investigation, only the engineering logs remain, and the sediments themselves appear not to have been preserved. Miller (1982) also reports on sedimentological work conducted on material derived from an 80 m borehole on the farm Uithoek by the South African Department of Geological Survey in 1980. Although sediments were preserved from this latter borehole, there is no record of any organic facies and the core logs are insufficiently detailed to warrant further consideration.

During November 1991, following close collaboration between the author and a consortium of scientists with research interests at Verlorenvlei, a preliminary geotechnical drilling investigation was initiated at Grootdrift. (A detailed account of the sampling strategy, including stratigraphic information, follows in Chapter 6). The primary objective of this particular drilling investigation was to recover continuous cores of organogenic sediment to a maximum depth of 50 m. Drilling commenced by means of a large diesel-powered hydraulic rotary drill-press and pneumatic hammer, while an extendible gantry provided support for the drill couplings and core casings. Theoretically, the rig described here is designed to drill down to 100 m and retrieve, intact, consecutive core-lengths, each measuring 1 m and contained within a 60 mm diameter plastic 'PVC' liner. The

following description of the coring procedure is based on detailed field observations made at the Grootdrift site, while additional technical information was gained via discussion with the principal operator. The steel outer barrel is driven by the rotating drill-press and cuts its way down through the sediment by means of an open-ended, diamond-tipped cutting head. The steel middle barrel supports the PVC liner - or inner barrel - and serves to funnel the sediment core, from the cutting edge of the outer barrel, up through the middle barrel and then inside the PVC liner. A spring-steel core catcher is located 10 cm inside the leading edge of the middle barrel and serves to prevent the sediment from slumping out during retrieval. Lubrication is provided in the form of water which is pumped between the outer and middle jackets in order to facilitate efficient coring and to prevent the barrels from becoming clogged with sand. Prior to each consecutive drilling event, a sterile PVC liner is inserted inside the middle barrel, which in turn is inserted inside the outer, cutting barrel. Following each drilling event, during which the drill is advanced a further 1 m, the steel core barrel is removed from its extension rods and winched to the surface. Here the PVC liner, containing the sediment core, is removed, sealed at either end, labeled and laid in stratigraphic sequence in specially designed core-boxes. Periodically, the borehole walls may require bolstering with an oversize, temporary casing to mitigate against collapse. This is achieved by advancing the oversize casing down to the bottom of the borehole and then flushing the extraneous sediment out of the casing with water. Where core retention is poor, especially under water-saturated conditions, the application of guar gum 'drilling mud' - a soluble polymer compound (galactomannan) with superior cohesive properties - is required to add stability to the borehole walls. Guar gum also exhibits a gelling effect which acts to coalesce with, and bind, coarse particulate matter, thereby improving the recovery of saturated, unconsolidated (sandy) material. The excellent friction-reducing and lubricating properties of guar gum are said to ensure more hydraulic power for cutting and bottom hole cleaning, resulting in improved penetration rates (DrilChem, 1990).

Drilling at Grootdrift continued over several days and ultimately produced two separate cores, one of 14.6 m and another of 26 m. On both accounts the drilling was terminated on reaching bedrock, a surprising outcome in light of information provided by the local farmer, P van Zyl, who had earlier reported boreholes of > 50 m in close proximity to the drill site. Nonetheless, the exercise was considered worthwhile, since it furnished a clear indication of the stratigraphy and nature of the Grootdrift valley sediments, while providing an invaluable opportunity to evaluate the appropriateness of the drilling technique for future palaeoenvironmental research in the area. Although the triple-barrel drilling procedure outlined here is considered to be one of the few effective industrial methods for deriving reasonably undisturbed, continuous cores from a variety of

sediments, in practice, the procedure was found to be fraught with complications. In the first instance, sediment recovery was seldom above 40 % of the actual depth drilled. In light of the fact that drilling costs were charged in accordance with depth drilled and not sediment recovered, this translated into a return of less than 40 %, or in the case of this investigation, R 1 363.60 per metre of sample recovered. Some of this 'loss' is undoubtedly the result of compaction; however, it was observed that some 15 - 20 cm of sediment was routinely lost through being trapped in the cutting head and not entering the PVC liner. Furthermore, the spring-steel core catchers proved, on the one hand, to be too aggressive in their action - thereby introducing a ploughing effect as the sediment passed through - and, on the other, too ineffective in their design, thus failing to adequately prevent sediment loss on core retrieval. Two additional complications arose with the application of water as a drilling lubricant. Firstly, fresh water, pumped from Verlorenvlei and then circulated through the drilling system, presented an obvious source of contemporary pollen, thus raising the possibility of contamination. Secondly, the damming effect created by the oversize support casing used to stabilise the borehole walls resulted in a substantial column of water through which each core needed to be raised. Not surprisingly, the erosion effect inherent within the water column, coupled with the inability of the core catcher to maintain the sample in the PVC liner, frequently resulted in the total loss of core material. Under these circumstances the use of 'drilling mud' was advocated and frequently applied, with reasonable success. However beneficial the application of 'drilling mud' might have appeared at the time of drilling, it also brought with it a new set of complications that were only to be recognised in the laboratory. One of the most basic properties of any 'drilling mud' is its solubility in water and it seems logical to assume that the guar gum used in this procedure would have dispersed into, and been taken up by, the interparticular water binding the saturated core material. Since the guar gum (galactomannan) compound is organic, this implies that foreign carbon of unknown age (possibly infinite) was being introduced into the sample during the drilling process. Radiocarbon dating techniques, critically reliant on uncontaminated samples for accurate age determination, are therefore rendered unreliable and consequently superfluous. The use of a traditional clay-based 'drilling mud' in this instance may have solved the dating dilemma but would have posed its own set of problems with respect to geochemical investigations and the introduction of exotic pollen. Finally, those samples incorporating guar gum residue - a sticky sludge of mucous consistency - required repeated, time-consuming cleansing in hydrogen peroxide or diluted sulphuric acid before further analyses could proceed.

An objective assessment of the suitability of the triple barrel drilling procedure is entirely dependent on the specific research objectives. In the context of this

palaeoecological study, the original coring prerequisite was to derive continuous cores with minimal disturbance, extending as far as possible into the organogenic deposit. It was also imperative that material suitable for dating be obtained from the cores. Given the constraints imposed by poor core recovery and the complications associated with guar gum, it was decided not to utilise the Grootdrift borehole material obtained from the triple-barrel procedure for pollen analysis, but rather to pursue a more refined and less problematic coring technique.

5.3 Techniques in portable vibracoring

Following the loan of a portable vibracorer from the University of Port Elizabeth (UPE) a series of field trials was conducted at Plettenberg Bay and later near Cape Town (refer to section 5.3.3 for study details). Based on the success of these trials, it was decided to construct a similar coring system for use at Verlorenvlei. The finance was made available in the form of a Foundation for Research Development (FRD) research grant, administered by the Department of Environmental and Geographical Science at the University of Cape Town (UCT). Design and construction of the vibracorer became the responsibility of the author, and once complete, the instrument was to be incorporated into the UCT equipment pool. In their paper; '*A new approach to portable vibracoring underwater and on land*', Lanesky *et al.* (1979) provide a detailed account of the component parts, design and operation of their vibracorer and this information was used together with the UPE instrument as a template for the new design.

5.3.1 Principles and methodology of vibracoring

Coring devices that operate on vibratory power sources are not a new concept. First developed by Kudinov (1957), the early models were cumbersome in design and invariably associated with ship-based exploration of shallow water, unconsolidated, continental shelf deposits. Most ship-based vibracoring systems such as the Vibrodrill (Sanders and Imbrie, 1963), the Haamer Vibrocorer (Jonasson, 1976) and the Hydraulic Vibracorer (Dokken *et al.*, 1979) make use of mechanical vibrators or air driven compressors with power resultants limited to the vertical plane. Under these mechanics, vertical power is transmitted to the core barrel as a series of longitudinal impacts producing a pile driving or hammering effect and consequent downward penetration. The Lanesky *et al.* (1979) design is unique in so far as it utilises a more refined vibrating procedure and can be operated as a portable land or water-based system. By

employing a continuous source, high frequency vibrator (± 12 000 vibrations minute^{-1}), a low amplitude (0.1 - 1.0 mm) standing wave is established throughout the core tube. This standing wave serves to fluidise and displace the saturated fine-grained sediments (sand, silt and clay) immediately adjacent to the core tube through a process of fluid dynamics known as liquefaction (Smith, 1984). On fluidisation, the resistance normally imposed by compacted sediments is substantially reduced and the core tube is able to penetrate - often under its own weight - with apparently minimal disturbance to the structure and composition of the captured sediments (Pierce and Howard, 1969; Lanesky *et al.*, 1979; Smith, 1984).

A primary requirement for efficient vibracoring is that sediments are unconsolidated and water-saturated, although penetration and recovery of non-saturated but moist fine-grained fluvial deposits has proved possible down to a depth of about 4 m (personal observation). Although the Lanesky *et al.* (1979) vibracorer was designed primarily for use in beach and offshore deposits, Smith (1984; 1987) has successfully modified the technique for use in fluvial and deltaic sediments where continuous cores down to 13 m have been recorded. At Verlorenvlei, an assortment of depositional environments, including fluvial, lacustrine, deltaic, estuarine and marine, has ensured a wide range of sediment characteristics. Vibracoring has been conducted by the author in all of these environments, with particular success in fine grained fluvial and deltaic (low energy, river-dominated) deposits where cores of 6 m and longer have been derived in less than two minutes of active coring. More problematic are the well-sorted medium (1 - 2 Phi) sands associated with the estuarine and marine deposits. Here the compacted sediments tend to clog the core barrel, preventing efficient penetration beyond 3 - 4 m. Pure clays, owing to the lack of porosity and minimal interparticular water are almost impossible to core. Large pebbles, boulders, compacted shell lenses and even dense, fibrous organic deposits also present an often insurmountable barrier to the passage of the core tube and require skillful negotiation by the operator. Occasionally the core tube will generate a diagnostic resonance on meeting with a solid, unyielding obstruction, although it is not uncommon for the cylindrical aluminium core tube to deform in an effort to admit an oversize cobble or conglomeration of pebbles (personal observation).

5.3.2 Blueprint and construction of the UCT vibracorer

The blueprint (refer to Figure 5.1 for schematic plans) of the portable vibracorer described in this section should be considered that of a hybrid system. Having evolved from the original Lanesky *et al.* (1979) design, various modifications have been made in an effort to improve sampling efficiency and core recovery over a wide range of

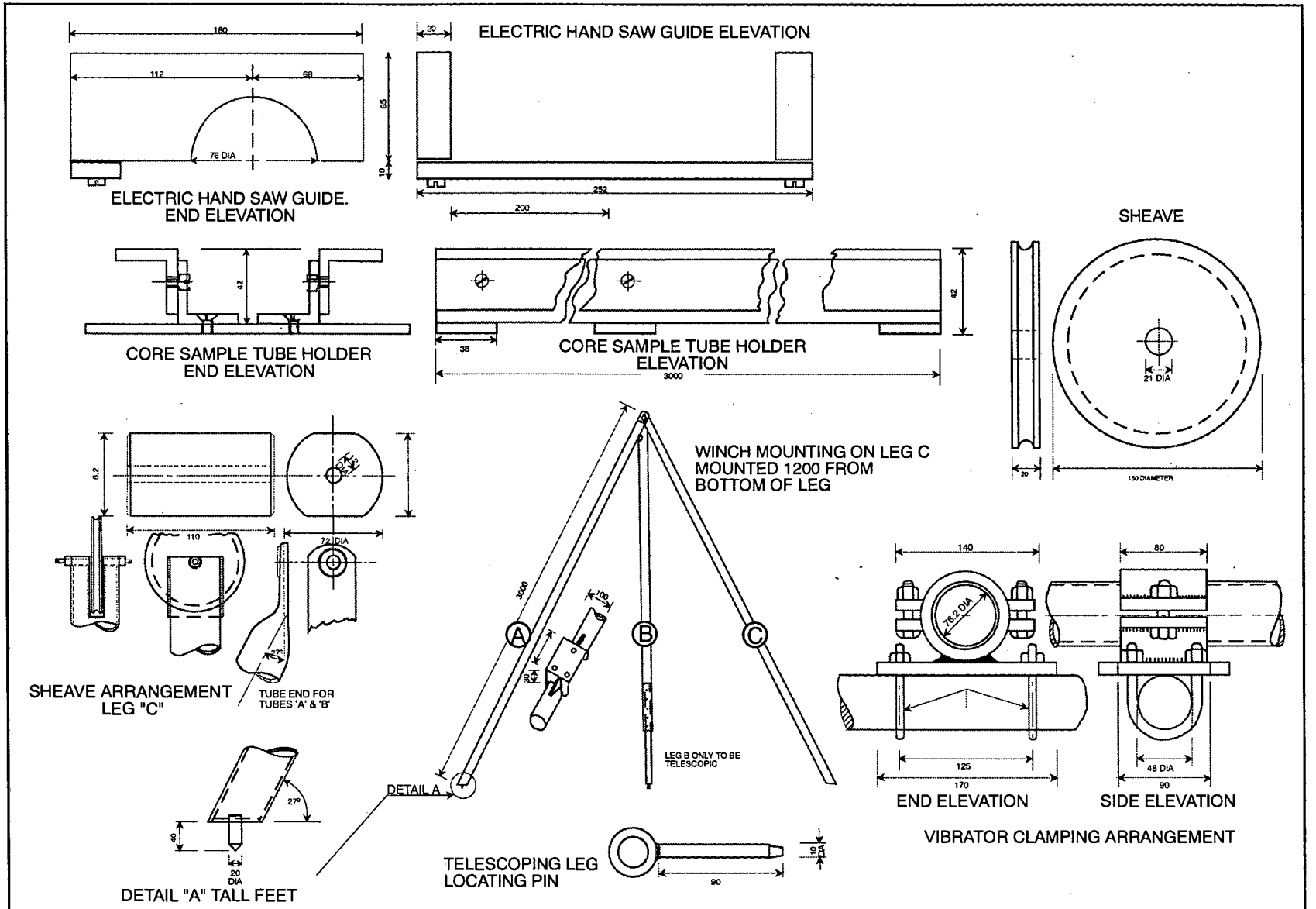


Figure 5.1 Blueprint and schematic plans of the UCT portable vibracorer.

saturated, unconsolidated sediments. The improvements suggested by Smith (1984; 1992) have, where applicable, also been adopted into the design. Although many of the component parts of the vibracorer can be purchased off the shelf, certain items require the services of a machine shop. In an effort to eliminate the potential for oxidation of normal steel, especially with frequent use in saline aquatic environments, many of the custom-made accessories, including the tripod and clamping devices, were constructed from stainless steel by Summit Engineering of Cape Town. The basic cost, to assemble and manufacture the components, amounted to R 12 000 (1996 prices) and the entire system tips the scales at around 100 kg.

The following major components of the UCT vibracorer (Figure 5.1) are described in detail:

Vibrator. Also referred to as a poker-vibrator, this is a commercially available device used by the construction industry for the effective consolidation of liquid concrete. It comprises a flexible transmission shaft housed in a high tensile spring-steel liner and coated with weathering and abrasion-resistant rubber compound. The transmission shaft, which is available in various lengths up to 6.2 m, has attached at one end a rotating, precision balanced pendulum which is supported by a tempered rolling race and housed in a tempered steel casing. This is the working end, or vibrator head, and it too is available in an assortment of sizes, each with a particular amplitude and frequency specification. The power is provided by a portable generator. Most petrol driven 4-stroke motors with an effective output of between 2.5 and 7 hp will suffice, depending on the requirements of the vibrator. In the case of the UCT vibracorer, a 144 cm^3, 3.7 kw Yanmar GE 50 motor delivering 5 hp at 3 600 rpm was coupled to a 44 cm vibrator-head with an effective amplitude of 1.0 mm and frequency of 12 000 vibrations $minute^{-1}$ (at 3 000 rpm).

Core Tubes. Either standard steel drill pipes, available in 3 m lengths with a diameter of 6.4 cm ID and a gauge of 4.4 mm, or standard thin-walled aluminium 'irrigation' tubing, available in 6 m lengths with a diameter of 7.8 cm ID and a gauge of 1.27 mm, are advocated (Lanesky *et al.*, 1979). Throughout this study, aluminium tubing was used in preference to steel drill pipes since it offers a number of distinct advantages including: cost, weight and superior penetration (due to its considerably thinner wall gauge). Until recently, the only advantage of steel drill pipes lay in their ability to be easily joined via threaded coupling joints, however, this is no longer a factor given a new technique of coupling aluminium core tubes developed by the author and discussed in section 5.3.5.

Clamp. The high frequency vibrations produced by the vibrator head are transmitted to the core tube by means of a custom-engineered clamping device which aligns and clamps the vibrator head perpendicular to the core tube. As the vibrating core tube settles into the substrate it will eventually become necessary to halt the motor, loosen the clamp bolts and move the vibrator head to a new point higher up the core tube.

Tripod. Once coring has been completed it is invariably necessary to use some form of mechanical leverage to retrieve the core from the sediment. A sturdy tripod in conjunction with a hoist system or winch is considered a minimum requirement for cores of more than 6 m. As the most unwieldy item of equipment, the tripod needs to be both stable and portable. The mandate for the construction of the UCT tripod required that the entire system could be dismantled into its component parts to aid portability. Each cylindrical leg measures 4 m in length and one leg has an extendible option to 5 m - an invaluable feature when working in uneven terrain. The base of each leg is welded closed to reduce the potential of the tripod collapsing into the sediment, especially under substantial load. This problem can be reduced almost entirely by placing large, inflexible plastic dustbin lids under each leg of the tripod. A manually operated, T 2605 geared trailer winch, with a maximum line pull capacity of 2 600 lb. is located on one of the tripod legs and feeds a cable through a large rotating pulley located on the main linchpin at the tripod apex. Depending on the length of the core, a number of winching procedures will need to be undertaken, and it is advisable to support the emerging core with the tripod.

5.3.3 An objective assessment of the vibracoring technique

Prior to construction of the UCT vibracorer, rigorous field trials were conducted including an experimental investigation designed to establish: i) the extent of sedimentary disturbance as a consequence of vibration-induced coring and ii) the respective efficiencies of a number of different core-catcher designs. The experiment aimed, in the first instance, to evaluate the effects of high frequency vibrations on visible sedimentary structures, the objective of which was to establish comparative measures of distortion, rotation and arching of layers between different sediment types. In the second part of the experiment, a range of core catcher designs was applied and tested. Each was evaluated in terms of: i) its ability to adequately capture and contain different sediments and, ii) its disturbance potential (scouring and distorting of sediments). Throughout the investigation aluminium core tubes of identical length and

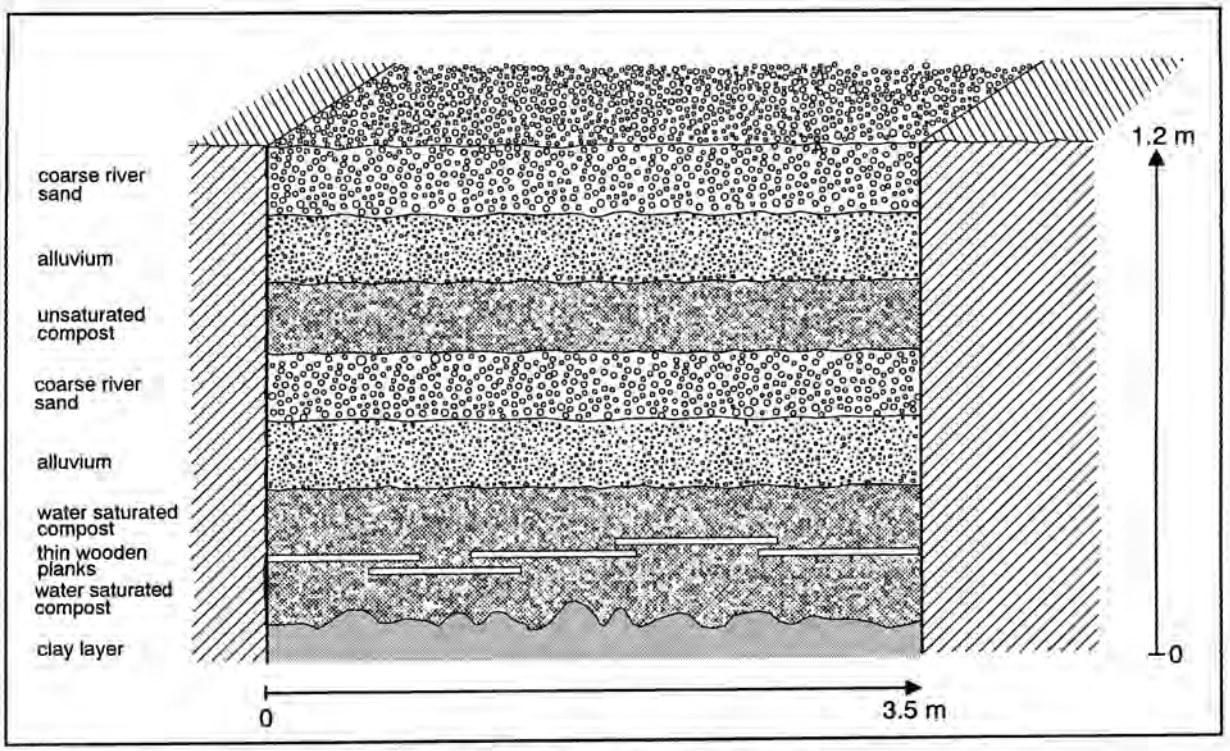


Figure 5.2 Dimensions and composition of the simulated depositional environment.

diameter were used. From these data it was hoped to establish an index of efficiency for the different core catcher designs under examination.

The experiment was conducted in a simulated environment incorporating three distinct sediment types: a highly organic, decomposing 'peat' layer, a fine-grained river terrace alluvium and a well-sorted coarse river sand (Figure 5.2). A large artificial clay-lined depression, constructed by a farmer for use as a decomposition pit, was selected as a suitable receptacle. A large hole measuring 3.5 m x 3.5 m wide and 1.8 m deep was excavated through the compost material to the clay foundation below. Thin wooden planks were then laid out across the clay floor of the pit so as to provide an obvious terminal base layer for the coring process (without the core actually penetrating the clay foundation). The final load of water-saturated decomposed litter (leaves, twigs and compost) was returned to the wooden floor of the pit, thus providing a compact 20 cm bottom layer of organic material. An approximate load of one ton of fine alluvium was then deposited into the hole and distributed uniformly across the organic base layer. The alluvium was then watered and compacted manually to reach a new base level of exactly 40 cm. Following this, a load of coarse-particulate (1 Phi) river sand was added to the excavation and watered and compacted in the same manner until the level reached 60 cm. The entire process was repeated again, this time adding a second layer of organic compost to reach 80 cm, followed by subsequent layers of alluvium and sand. During each layering process, dozens of broken matches, measuring ±1 cm in length,

were laid horizontally into the sediment and aligned, north-south, with match heads in the north direction. The end result was a 120 cm cake-layer of compost, alluvium and sand in a precise double tier configuration. The sediments were watered extensively and allowed to settle overnight.

The decomposition pit proved to be a very practical simulated depositional basin. Earlier attempts to conduct the vibracoring experiment in open-ended 44 gallon drums had failed irrevocably as a consequence of the metal walls inducing disruptive return vibrations in the highly confined space. The decomposition pit offered the advantage of being sufficiently large, self-contained and waterlogged (by virtue of the clay lining), yet it remained entirely insulated from return vibrations - a consequence, probably, of the huge volume of spongy, vibration-absorbent, organic compost surrounding the excavation.

5.3.3.1 *A simple efficiency experiment*

Methods and materials. The first part of the experiment sought to assess the extent of sedimentary disturbance as a consequence of vibration-induced coring. In an effort to resolve the source of possible disturbance, core catchers were not applied during this experiment. Two cores derived by vibracoring were compared with two cores derived by independent means. The first vibracore (VC1) was achieved with maximum output at 3 600 rpm, the second vibracore (VC2) was achieved at minimum throttle and consequently a lower vibration frequency, the third (percussion) core (PC) was hammered manually into the sediment by means of a ten pound hammer and the fourth (hydraulic) core (HC) was forced down hydraulically by lowering the blades of a forklift truck onto the top of the core tube. The (rotational) north-south alignment of each core was fixed, prior to coring, by means of a vertical line etched down the length of each core tube. Consistent core retrieval was maintained, in each case, via constant hydraulic lift from the forklift truck and the respective cores were labeled and secured for the short journey to the cutting facility.

In order to establish the effects of vibracoring on the sedimentary structures as well the comparative efficiencies between core catchers, it was necessary to cut open the core tubes for detailed *in situ* inspection of the captured sediments (refer to section 5.3.4. for precise details on the cutting procedure). Each core tube was cut lengthwise along opposite sides (following the plane of north-south alignment), thereafter the sediment core itself was carefully garroted in half to reveal two identical, mirror-imaged cores.

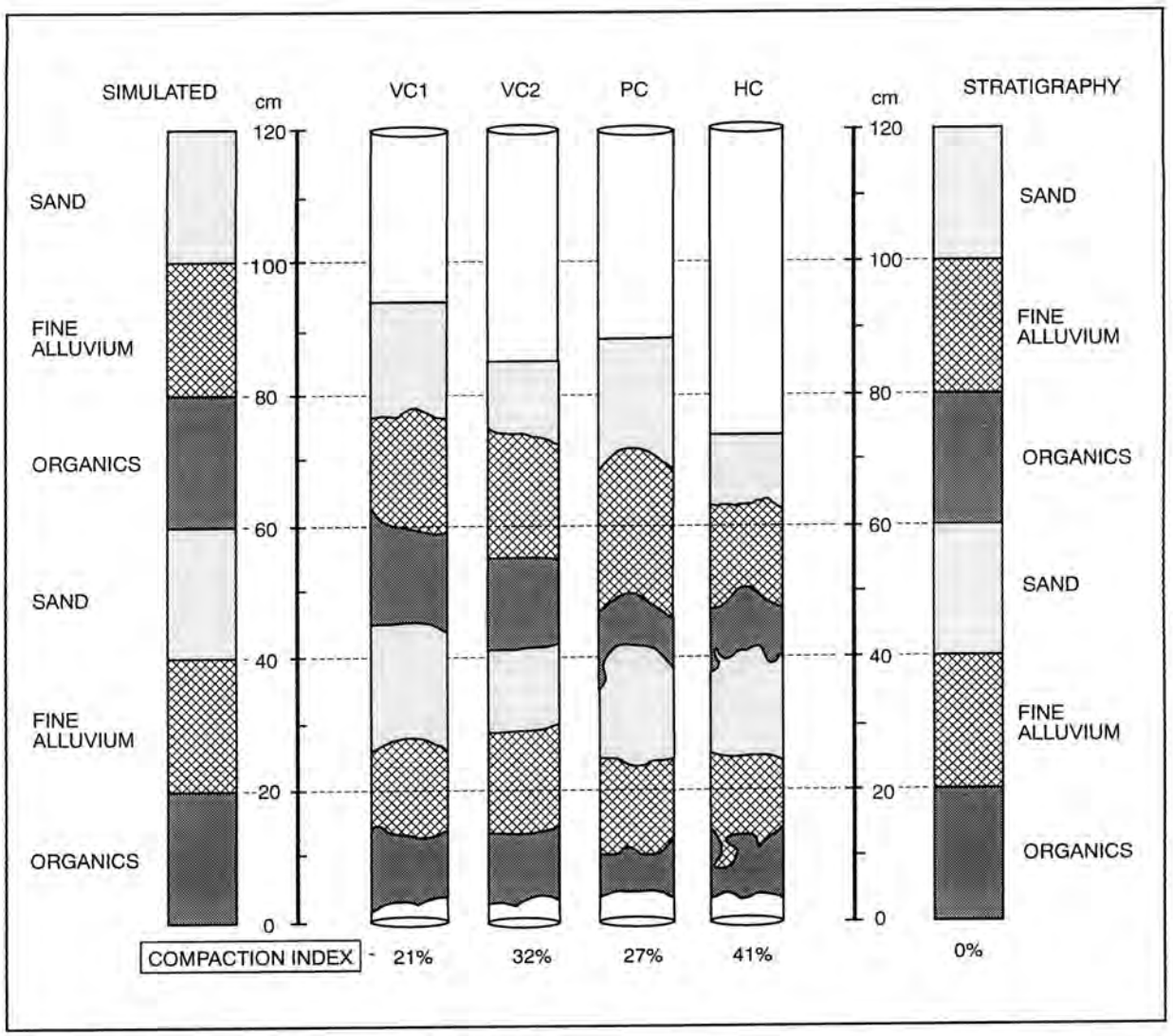


Figure 5.3 Core log comparison: VC1, VC2, PC and HC.

Results. The results, recorded photographically in the field, have been scanned, digitised and recomposed graphically in Figure 5.3. The (photo) graph compares the core-logs of the two vibracores, VC1 and VC2 with those of the percussion core, PC and the hydraulic core, HC. Core catchers were not fitted and all the cores have suffered a more-or-less similar loss (about 5 cm) of saturated organic material through slumping from the base during retrieval. Furthermore, it is evident that all the cores have experienced some degree of compaction. The respective compaction indices, as presented in Figure 5.3, were derived by means of the following calculation:

$$\frac{(\text{DEPTH OF DEPOSIT CORED} - \text{LENGTH OF CORE MATERIAL})}{(\text{DEPTH OF DEPOSIT CORED} \times 100)}.$$

These indices, given as percentages, describe the amount of physical compaction (reduction in length) of the cored deposit following the different coring regimes. The vibracore (VC1) demonstrates the least reduction at 21 %, while the hydraulic core (HC) is most compacted, reducing in length by 41 %. These levels of compaction are not considered unreasonable, especially in light of the simulated stratigraphy. Of greater interest however is the degree to which the organic layers have distorted in cores PC and HC while all the sediment layers in VC2 and to a lesser extent in VC1 have maintained their integrity and exhibit less distortion at the core-wall contact. VC1 was derived at maximum throttle and required less than ten seconds to bottom out on the basal wooden planks, though it was noted that penetration slowed, briefly, on reaching the gradation marks at 60 - 70 cm, the depth corresponding to the coarse river sand. Sediment structures demonstrate distortion only along the core walls and compaction throughout is minimal. VC2, which was derived at minimum throttle, required some 25 seconds to core and appeared to penetrate all the sediments at a uniform rate. Sediment integrity is best maintained in VC2, although compaction of the sandy sediments is highest, reaching almost 50 %. The derivation of PC, which was obtained via manual hammer percussion, proved to be a cumbersome and time-consuming procedure and it is doubtful whether this core would have penetrated any deeper without serious malfunction of the core tube. The sedimentary structures of PC are reasonably coherent in the saturated lower tier, but become noticeably arched and distorted in the upper layer organics and especially in the dryer, less consolidated upper alluvium and sand components. HC, derived via constant hydraulic pressure, reveals severe distortion among the organic layers and represents the most compacted of the four cores - a consequence probably of 'plugging' by the organic material. Plugging commonly occurs in heterogeneous deposits where an horizon with a high friction coefficient, such as a fibrous organic layer, lies above a less resistant or better lubricated substrate, such as saturated mud or alluvium (refer to example A in Figure 5.4). As the core tube is forced downwards, the organic horizon may enter and block the core barrel. Continued coring seldom relieves the blockage and the core merely forces a passage through the underlying substrate without actually capturing any additional sediments (personal observation). Based on the marked levels of distortion exhibited in the organic layers of PC and HC, it would seem that vibracoring may have an advantage over percussion and hydraulic coring in capturing, and maintaining the stratigraphy of organic-rich sediments. In both the vibracores, sediment rotation was minimal in the sand and alluvium components but some anti-clockwise rotation, in the order of 20 degrees, was noticed in the upper layer organics. No sediment rotation was discernible in HC, or in the lower tier of PC. However, the alignment of the matches in the uppermost sand and alluvium layers of PC was chaotic - suggesting possible shuffling of the drier uppermost sediments.

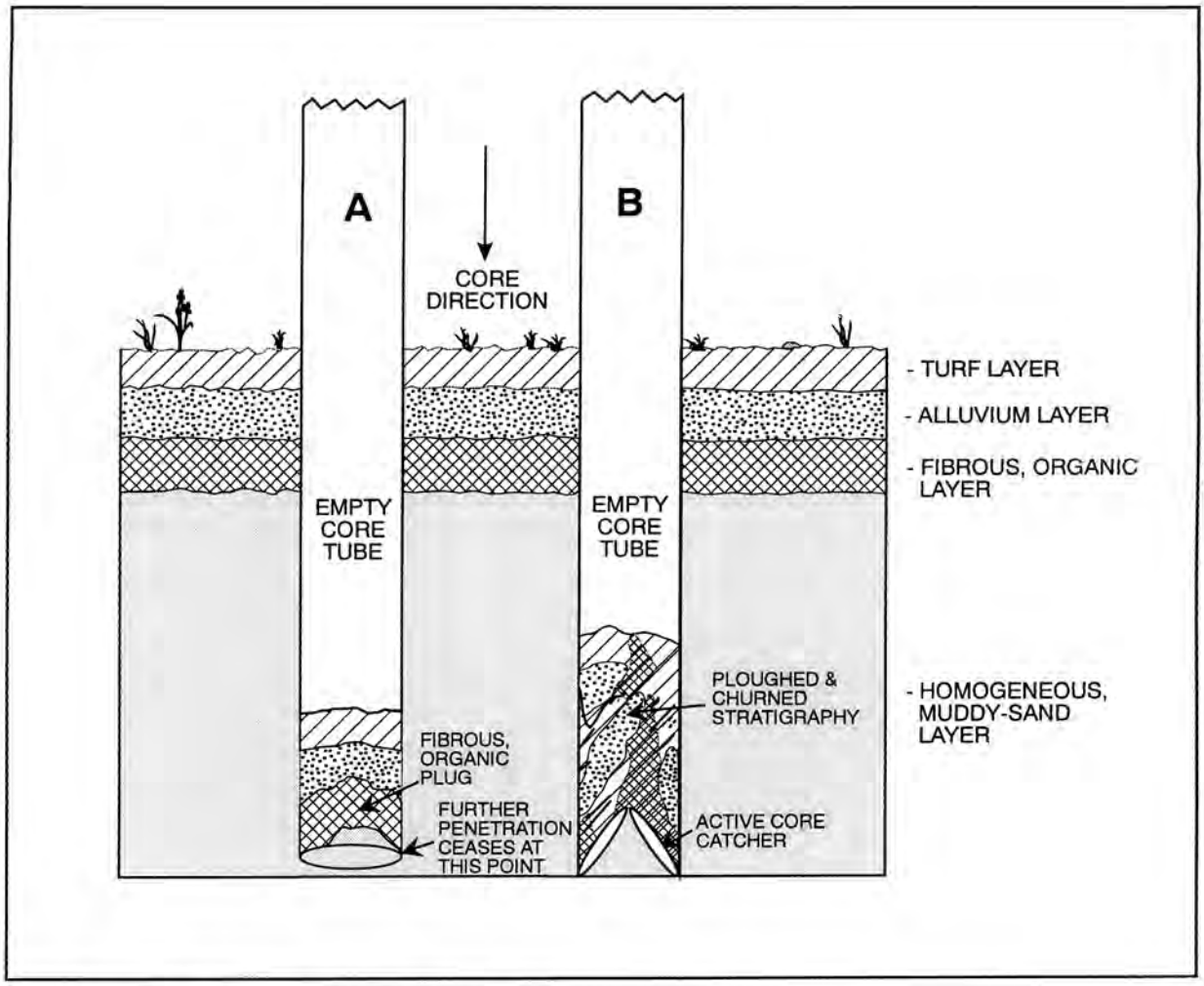


Figure 5.4 Core plugging (A) and core ploughing (B) in heterogeneous sediments.

Conclusions. The conclusions reached by means of this experiment are based largely on an objective visual interpretation of the captured sediments. Given the preliminary nature of the experiment, together with the artificial construction of the sedimentary deposit, it was felt that more complex scientific and quantitative methods of comparative investigation such as x-ray radiographs, epoxy peels and gamma-ray logging (Molnar and Smith, 1993) would be largely unjustifiable. Nonetheless, even this simple experiment has revealed some important conclusions about vibracoring and these are summarised as follows:

1. Vibracoring provides an efficient and superior alternative to percussion coring and hydraulic augering.

2. Despite assurances that hydraulic and percussion coring techniques produce only minimal disturbance in wet, unconsolidated sands (Hanna, 1954; Shier and Oaks,

1966), the same appears not to hold true in coarser, poorly-sorted organic deposits and drier sandy substrates.

3. Sediments derived by vibracoring maintain their integrity and stratigraphic sequence with comparatively little distortion. Dragging is minimal and constrained to the sediments immediately adjacent to the core tube walls. In this regard, vibracoring using large diameter cores (7.5 cm) is clearly advantageous as subsampling can take place from sediments located within the centre of the core tube.

4. Compaction is greatest in well-sorted, coarse grained sediments and least in fine-grained alluvium, though modulating the vibration frequency may reduce compaction in sand.

5. Measurable rotation of entrained material is apparent in organic litter but appears not to be significant in better-sorted, more compact sediments - this limitation should be considered when attempting to align bedding planes along a core transect.

5.3.3.2 *Core catcher assessment*

Methods and materials. The second part of the investigation aimed to evaluate the efficiencies of a number of different core-catcher designs. Core catchers have been developed in response to problems associated with slumping and loss of material on extraction. The basic principle involved is almost universal and can be equated, crudely, to the barbs of a fish hook (Figure 5.5). A series of sprung teeth (usually steel, brass or plastic) are fixed inside the perimeter of the leading edge of a core tube. Theoretically, the teeth allow for sediment to enter and progress up the length of the core barrel by flattening against the inside of the tube. On extraction, the sediment within the core barrel will invariably attempt to slump out under gravity, at which point the teeth, which are lightly sprung, collapse inwards under the pressure of the descending sediments to form either a complete seal or at least to provide critical resistance.

In this experiment, four different core catchers (A, B, C and D, Plate 5.1) were attached to individual core tubes. Two additional core tubes (not illustrated) were to be used as controls and were therefore not fitted with core catchers. The four different core catchers comprised the following: A) A standard design (spring-leaf type) core catcher as utilised by the South African Department of Geological Survey (P Bova, personal communication). These core catchers are heat moulded from polycarbonate and

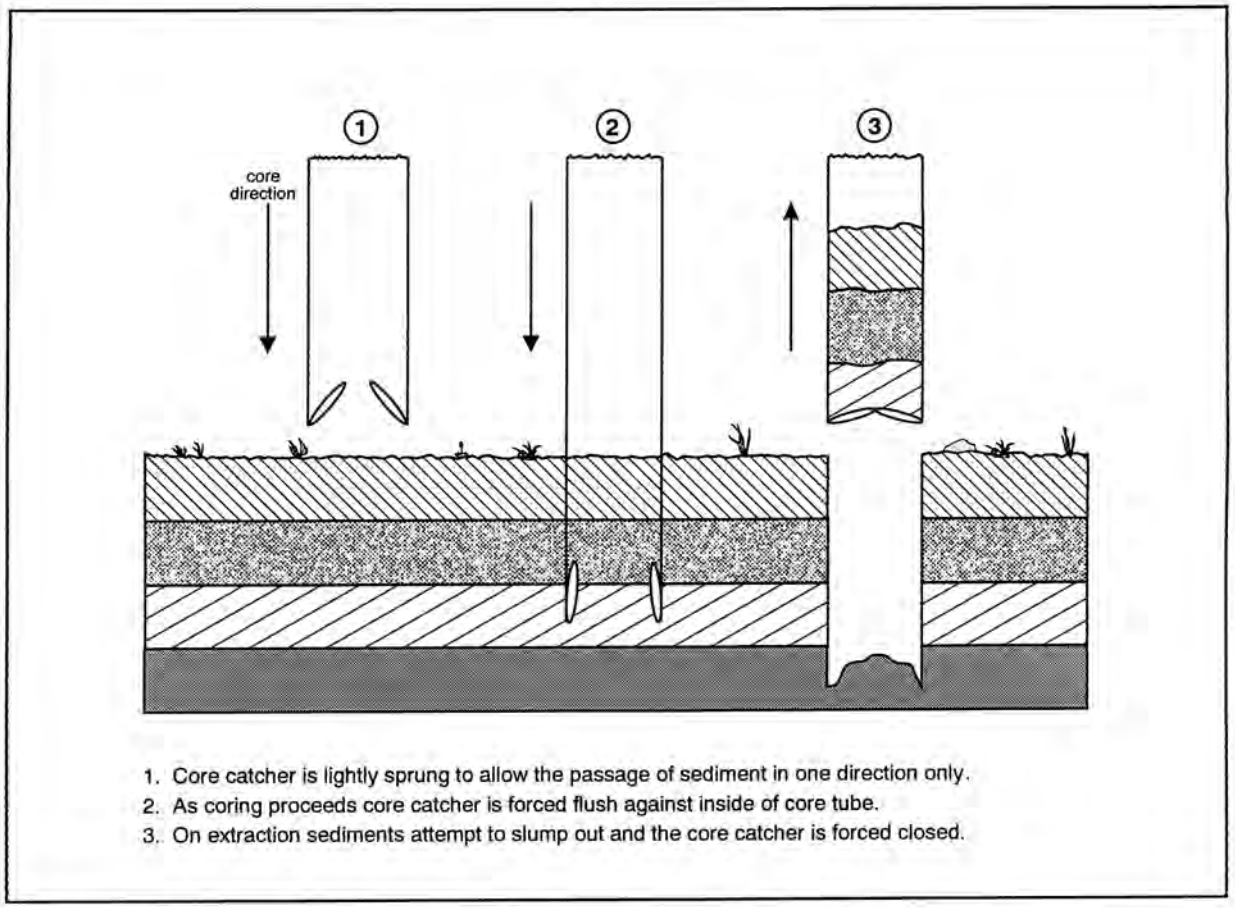


Figure 5.5 The basic core catcher mechanism.

employ a rosette of 14 actively closed teeth. B) A 0.15 mm gauge brass shimstock core catcher with four semi-active teeth and, C), A 0.5 mm gauge brass shimstock core catcher with seven semi-active teeth. D) A 0.15 mm gauge brass shimstock core catcher with 12 semi-active teeth. The last three core catchers are all variations after the design of Reddering and Pinter (1985). The four core catcher tubes, together with the two control tubes were then vibracored into the test pit at a constant frequency produced at 50 % throttle. All the tubes were then extracted hydraulically, in the same manner, although the open ends of two tubes were also fitted with an airtight rubber piston prior to extraction. The application of a piston to improve core recovery is described in Ginsburg and Lloyd (1956) and serves merely to prevent air from entering and expanding inside the tube during extraction. With the airtight piston in place, slumping of sediment will result in a vacuum at the surface of the core and may prevent further slumping and even reduce compaction. After labeling and packaging, all the cores were transported to the cutting facility where they were split open for further inspection.

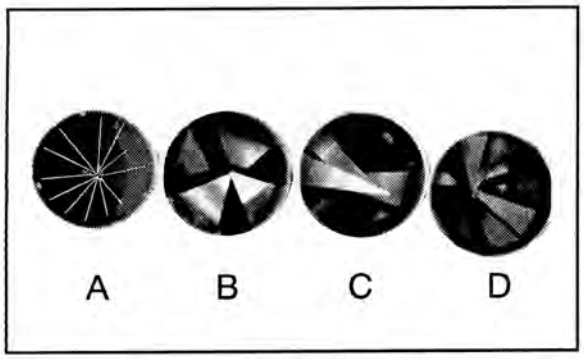


Plate 5.1 Comparison of four different core catcher designs.

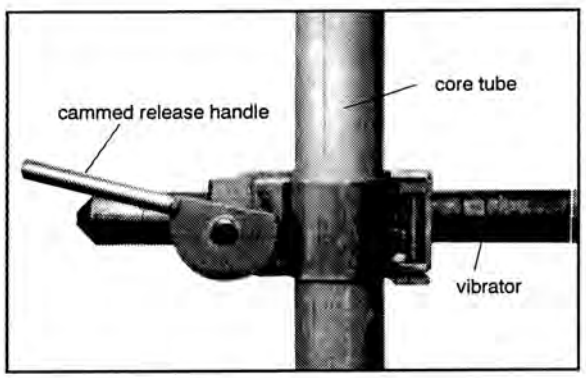


Plate 5.3 Vibrator clamp handle.

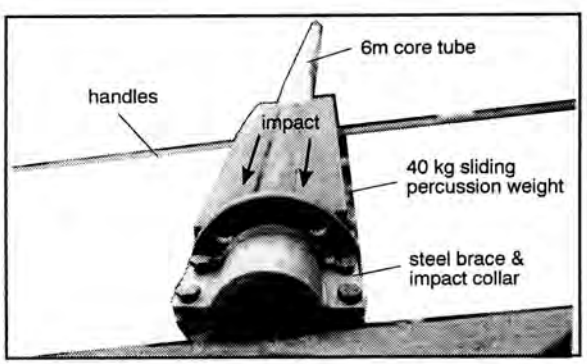


Plate 5.4 Percussion weight and impact collar fitted to a 6m core tube.

Plate 5.5 Expanding rubber stopper and spanner.

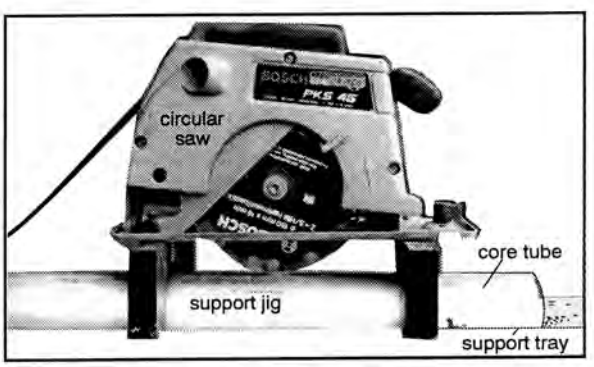


Plate 5.6 Support tray, jig and circular saw.

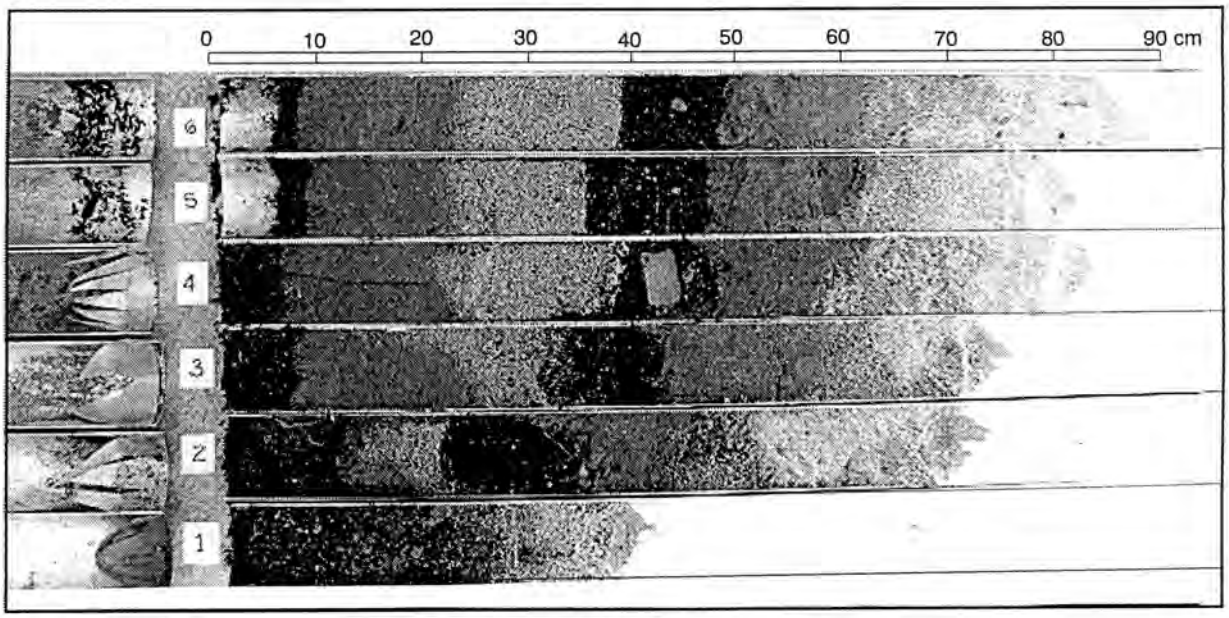


Plate 5.2 Efficiency comparison of four different core catcher designs.

Results. The results of the evaluation of the various core catchers are best illustrated by reference to Plate 5.2. From this scale photograph a number of fundamental characteristics can be discerned. Firstly, without the application of a core catcher (cores 5 and 6), the saturated organics at the base have not been adequately retained in the core tube during retrieval. Secondly, the more energetic the action of the core catcher (cores 1 and 2), the greater has been the disturbance of the sedimentary structures. Core 1 was fitted with an actively closed polycarbonate catcher. In this instance the bulky design has effectively increased the frontal area of the core barrel, resulting in enhanced plugging and a consequent reduction in penetration. The compaction index of core 1 is substantial, amounting to a 66 %. Furthermore, the aggressive nature of this core catcher design has introduced a 'ploughing' effect that has confused the coarse stratigraphy and obliterated the finer sedimentary details. Ploughing occurs as a consequence of the core catcher teeth (or barbs) attempting to force closed during the coring procedure (refer to core B in Figure 5.4). Under these circumstances, core material is scoured, churned and mixed as it passes through the core catcher. Core 2, fitted with a semi-active 0.5 mm shimstock core catcher, has likewise produced a problematic stratigraphy with arching and mixing particularly apparent in the basal alluvium and organic layers. The catchers from cores 1 and 2 also prevented the passage of the broken matches, purposefully entrained and aligned within each layer, from progressing through the teeth of the core catcher along with their accompanying sediment matrix. This resulted in a build up of matches (and other coarse material) in the core catchers and has undoubtedly contributed to the observable scouring effect. Cores 3 and 4, both fitted with semi-active 0.15 mm brass shimstock catchers, reveal a significant improvement in detail and stratigraphy. The

thinner gauge shimstock clearly allows for a more delicate action, with less interference of transient sediments (note the large pebble in the middle organic layer of core 4). Capture performance does not seem to be impaired by the thinner gauge, although, on closer inspection, the 12 tooth rosette seems to close and seal more effectively than the four-tooth variant. A third fundamental characteristic is revealed by a comparison between core 4 and the two non-core catcher tubes (5 and 6). Even though the basal organic layers have partially slumped in these latter two cores, stratigraphic integrity remains far superior in the absence of core catchers. All the core catchers tested here, including the popular and accepted forms after Reddering and Pinter (1985), have exhibited varying measures of drag effect, scouring and compaction through the mixed-layer sediment. Finally, core 4 and core 6 were both fitted with an airtight rubber stopper (piston) at the top of the tube prior to extraction. In the case of core 4, it may be that the application of the rubber stopper, and the resultant vacuum, has aided in recovery, although there appears to be little discernible difference between the recovery potential of core 5 (no stopper) and core 6 (with stopper). Core 6 produced the best recovery at 75 % and a compaction index of only 25 %.

Conclusions. With respect to the evaluation of core catcher designs, the experiment produced the following conclusions:

1. All core catchers, through their location inside the leading edge of the core barrel, are likely to result in some form of sediment distortion and almost certainly a greater index of compaction.

2. The more aggressive (and ultimately effective) the capture action of the core catcher, the greater the possibility of plugging and reduced penetration as well as ploughing and mixing of sediments.

3. Core catchers should only be used as a last resort where conventional core tubes and pistons fail to adequately capture saturated, unconsolidated organic and sandy material.

4. Should the application of a core catcher be considered necessary, it should be recognised that detailed stratigraphic integrity may be forfeited as a result.

5. The most efficient core catcher design is that which minimises impact during penetration and maximises capture on recovery. Of the models under examination in this experiment, the 12 tooth, semi-active, 0.15 mm gauge brass shimstock variant, adapted after the design of Reddering and Pinter (1985), is considered to be the most balanced and therefore most efficient core catcher design.

5.3.4 Structural enhancements and procedural tips for vibracoring

During the course of this study, the UCT vibracorer has been used extensively by the author in and around the Verlorenvlei system, as well as in other parts of southern African. More than 400 m of core material, varying in length from 2 - 20 m, has been derived from a diverse range of sites and a variety of different sediments. As a result of complexities arising during the course of this field work, a number of structural enhancements and procedural tips for improved vibracoring have been developed, and these are outlined briefly in the following section.

The vibrator-clamping procedure, described in section 5.3.2 above, proved to be a clumsy and time consuming process and a revised clamp system incorporating a cammed release handle instead of nuts and bolts has been designed and implemented with great success to the UCT vibracorer (Plate 5.3). The advantage of the clamp-handle system lies in the swiftness with which the vibrator head can be disengaged and moved up the core tube. It also alleviates the frequent and annoying problem associated with dropped bolts. An additional cam-tightening clamp, with two 75 cm long handles attached, has also been manufactured. The clamp-handles are fixed around the core tube and allow the operating personnel to exert additional downward pressure, either by pushing down on the handles or standing on them.

As a general rule (and equally applicable to any other mechanised coring procedure), it is advocated that the minimum amount of vibration (either in time or frequency or both) be used to derive a core. In this regard, one of the most elementary, yet fundamental adjustments that can be made to improve penetration is to establish the most suitable vibration frequency by regulating the motor. Contrary to expectation, reducing the vibration frequency may even enhance the rate of penetration in coarse sandy sediments (personal observation) while the opposite is true for fine-grained organic muds. Given that no simple relationship appears to exist between increased vibration frequency (or engine rpm) and increased rates of penetration, it seems probable that substrate composition may be the critical determining factor when selecting an appropriate vibration frequency. If the composition of the substrate is undetermined or highly variable, it is often useful to fluctuate the rpm of the motor in two second pulses, thereby inducing the vibration frequency to rise and fall cyclically. During each cycle, as the vibration frequency peaks and then tapers off, the operator will have an opportunity to observe any changes in the rate of penetration and then select the best frequency accordingly. Pulsing the motor is also useful in re-establishing coring momentum after unavoidable stoppages to move the vibrator-head and clamp to a new elevation on the core tube.

If penetration fails to proceed after re-starting and pulsing the motor, it may be necessary for the operator(s) to rotate the core tube clockwise and anticlockwise while applying downward pressure on the clamp handles. Should this not work, or should penetration terminate unexpectedly because the core tube has encountered a solid obstruction, a 40 kg percussion weight can be used, in conjunction with the vibracorer, in an attempt to break through. Manufactured from a 40 cm length of standard 4.5 inch (OD) steel tubing to which steel weights and two long handles have been welded, the hollow cylindrical design of the percussion weight allows it to slide up and down the length of the core tube. A tough steel brace and wide support collar is bolted around the core tube, just above the ground. The percussion weight is then raised manually and dropped onto the steel brace which in turn transmits the percussion force down the core tube (Plate 5.4). Under extreme circumstances, the percussion weight can be winched, via a pulley, to the top of the core tube and released from a height of two or three metres. This rudimentary percussion technique is only recommended as a last resort and runs the risk of irreparably damaging the core tube - although it has, on occasion, proved effective in breaching unyielding clay or shell horizons (personal observation).

Probably the most elementary penetration tip of all, however, is to remember to bevel the leading or cutting edge of the core tube to a razor-sharp point with a file. This not only reduces the frontal area ratio at the critical point but allows the operator(s) to cut through obstructive organic matter by rotating the core tube in a vigorous manner (personal observation).

Core retrieval can be a fickle, time-consuming process often making extreme demands on both machine and personnel. Successful coring does not imply successful capture and there are rare occasions during which all the core material may slump out of the core tube during retrieval. Under these circumstance, it becomes necessary to make use of a core catcher and, at very least, an airtight rubber piston to establish an adequate vacuum. Home-made rubber stoppers, designed by the author and used extensively to date, have been machined from a solid block to form an 8 cm rubber 'core' with a diameter fractionally less than that of the ID of the standard aluminium core tubes. A long bolt, with adjustable nut and large washers located either side, is inserted through a pre-drilled hole extending through the middle of the rubber 'core'. On tightening the adjuster nut, the washers on either side of the rubber 'core' are forced towards one another thereby compressing the rubber and causing it to expand laterally (Plate 5.5). A smear of petroleum jelly facilitates easy insertion of the rubber stopper into the aluminium core tube and ensures an airtight seal on expansion.

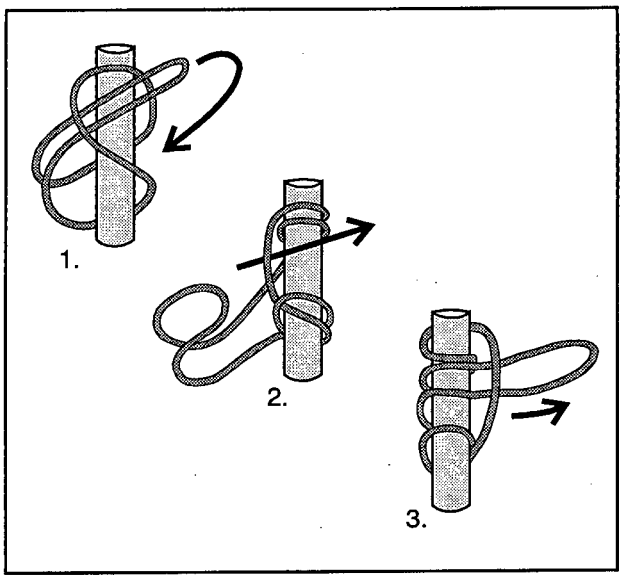


Figure 5.6 Three steps to secure the Prussik loop.

With the continual refinement of the vibracoring technique and the subsequent generation of longer cores, it has become necessary to improve the capacity of the winch system by incorporating a double block of pulleys between the primary sheave on the linchpin and the attachment point on the core tube. Unforgiving steel cable has been discarded in favour of 11 mm nylon caving rope, made by Marlow, which is both more manageable to handle and provides the correct measure of elasticity necessary to maintain momentum once the recalcitrant core tube is released from its vacuum. Attachment of the Marlow rope to the core tube can take place in any number of ways, although the most elegant option is that suggested by Smith (1984) who advocates an ingenious mountaineering solution - a remarkable knot of unverifiable origin - called the Prussik loop (Figure 5.6). Commonly employed by rock climbers, the Prussik knot offers the benefit of tightening progressively under load, yet once tension is relaxed, it is easily released and moved to a new position. The use of nylon webbing loops with a certified breaking strength in excess of 2 000 kg is strongly recommended - primarily from the point of view of personal safety during the winching process.

Following the successful retrieval of a core, two (sub)sampling options are available. The first option allows for the reuse of the aluminum core tubes, is comparatively cheap and is easily performed in the field. Once the core has been extracted from the ground, the core catcher (if applicable) is removed, the vibrator-head and clamp are re-attached to the upper section of the core tube following which the sediment core can be carefully vibrated out into a receptive, plastic trough (oversize PVC pipes cut lengthwise, in half, make for useful receptacles). At this point it becomes feasible to subsample the core and describe the stratigraphy, although a number of complications are inherent, not least the uncertainty regarding actual core length, measures of

compaction and the possible contamination of material from the sides of the core tube. A better and more reliable method of subsampling involves the splitting (and consequent destruction) of the core tube with the sediment *in situ*. This procedure is facilitated by a custom-made support tray, jig and circular saw combination (Plate 5.6), designed to cut precisely through the aluminium core tube walls without interfering with the sediment core inside. The core is cut lengthwise by traversing the saw and jig combination along opposite sides of the aluminium tube following which the incumbent sediment core is systematically garroted, using a fine piano wire, from top to bottom, into two identical halves. Once the core is split apart, the surfaces can then be cleaned and described, and subsampling can take place from the centre of the core, thereby avoiding any potential dragging and contamination of material that may have occurred at the core-tube margins. Although there is a cost implication in the order of R 18.00 m^{-1} (1996 prices) attached to this latter procedure, it offers a number of distinct advantages:

1. Sediment cores can be transported securely and with little, if any, discernible disturbance from the coring site to the laboratory if they remain sealed and stabilised in the aluminium core tubes. Core tubes are simply cut into manageable lengths and sealed by means of a durable plastic cap or rubber stopper combination. If refrigerated, cores can be stored almost indefinitely in this manner.

2. Splitting the core produces two identical halves, one of which can be used for subsampling while the other can be preserved in plastic sleeving and stored as an insurance policy in the form of an archival half.

3. Since the sediment core remains *in situ* in the aluminum tubing, there should be no reason, other than compaction (which in this case can be established relative to the actual depth cored), to doubt the integrity of the stratigraphy. Similarly, this procedure alleviates the problems of contamination associate with subsampling in the field - both via re-vibration of the core material and from passive fallout of aerospora and other potential contaminants.

4. Techniques such as thermoluminesence dating require that samples be derived in total darkness. Sealed core tubes can be transported to a laboratory or dark room facility for cutting and subsampling under controlled conditions - a task not readily feasible in the field.

5.3.5 An optimal coupling technique for aluminium vibracore tubes

Occasionally it may prove desirable to core to depths beyond the standard mill length of commercially available aluminium tubing which, in South Africa, is 6 or 12 m. Since 6 m is considered the maximum length which can reasonably (and legally) be transported by a regular light commercial vehicle, this can present a logistical problem. Under these circumstances, the use of joinable steel drill pipes may present an alternative option. Paradoxically, however, the additional thickness of the wall gauge required for threading the steel drill pipe couplers imposes a severe constraint on deep penetration by increasing the frontal resistance (area ratio) of the drill pipe (Lanesky *et al.*, 1979; K Reddering, personal communication) and inducing premature coning at the tube mouth (Aaby and Digerfeldt, 1986). In response to this predicament, various attempts have been initiated by the author to join lengths of thin wall gauge (1.27 mm) aluminium tubing together.

Methods and materials. The brief for an optimal coupling technique required that a number of criteria be adequately satisfied. The technique would need to be: i) quick and easy to apply in the field, ii) cost effective to produce and replicate, iii) performed with a minimum of tools and equipment, iv) sufficiently durable to withstand the rigours of vibracoring, and v) of an ergonomic design such that the area ratio (impedance and coning potential) at the join would be kept to the absolute minimum. A variety of concepts was considered, including pairs of threaded steel couplers, designed to be inserted into and riveted on to the tube ends, as well as the use of a reusable, bolt-around steel sleeve. This latter option has since been adopted, independently, by Smith (1992), but fails to satisfy the criteria for an ergonomic design. Smith (1992) reports a perceptible increase in friction during hoisting - a consequence, undoubtedly, of the wide flange used to bolt the coupler together. Ultimately, the most successful technique proved also to be the most elementary. By cutting lengthwise through one side of a 1.5 m wasted, off-cut aluminium tube (the same diameter and gauge as the actual core tube), a thin walled sleeve can be created. The rigidity of the aluminium tube is reduced on cutting and the sleeve can be prized open by inserting a flat spanner or file into the cut perforation and then twisting through 90°. The two cores to be joined can then be manipulated into the sleeve from opposite ends, by twisting and pushing, until they meet flush against one another in the middle (Figure 5.7). Each 6 m core tube is therefore buttressed, in a vice-like grip, by 75 cm of sleeve at the join. The sleeve has a small gap of some 3 cm running its length, a consequence of it having to expand to accommodate the two core tubes, yet despite this, it adopts a new, enlarged cylindrical state without deforming or warping into an ovoid. Although this 'dry' join is likely to

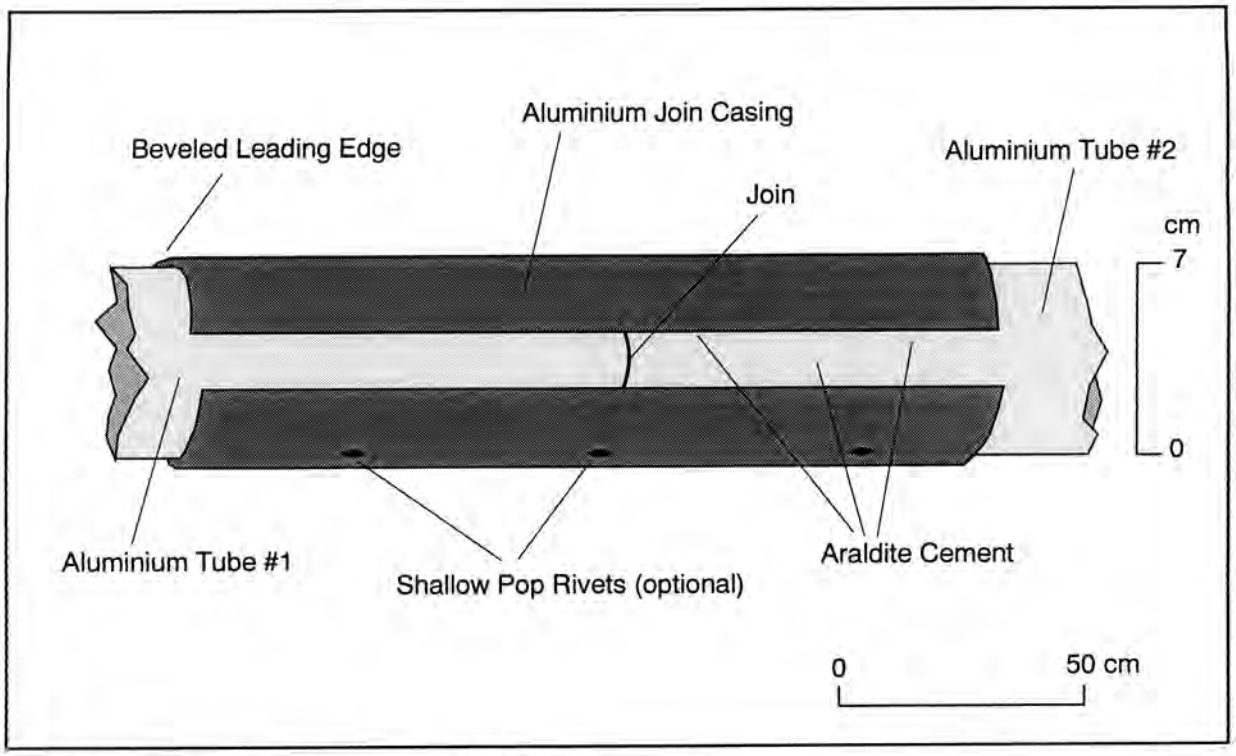


Figure 5.7 An optimal coupling technique for vibracore tubes.

provide sufficient support for vibracoring, it will be unable to sustain the winching process and extra reinforcement will be required. It is recommended that the sleeve be bonded to the core tubes with quick setting 'araldite' epoxy adhesive and shallow head pop-rivets - although the latter are no longer considered a prerequisite. In order to enhance the purchase power of the araldite, it is also advisable to roughen the smooth surfaces on the inside of the sleeve and the final 75 cm on the outside of the core tubes using a coarse grade emery paper or file (it may be useful to use a broom handle or similar attachment to facilitate scouring inside of the sleeve). The application of araldite to the core tubes also facilitates the process of inserting them into the sleeve by easing the friction coefficient imposed by the two rough metal surfaces. Having forced the core tubes into the sleeve, it is useful to torque up the bond by applying 6 - 8 large plastic 'zip ties' (a few metres of rope bandage would have a similar effect) around the join. Once the araldite has set - normally 15 minutes is sufficient - the zip ties, having performed their function, are no longer necessary and should be removed. The joining technique described here satisfies every requirement of the original design criteria. If cores and sleeves are prepared (cut and sanded) prior to the field excursion, each join operation can take as little as five minutes, although an extra 10 or 15 minutes is recommended for the araldite to reach maximum strength. The cost per join is minimal if waste aluminium off-cuts are used, and at worst, amounts to the price of the sandpaper, adhesive and zip ties. No specialist tools are required in the field unless pop-rivets are to be used, in which case a riveter and a battery-operated drill will be necessary. The simplest method of

cutting the aluminium sleeves lengthwise is to use the circular saw and moulded jig (details of which are provided in section 5.3.4). Failing the availability of this equipment, a hacksaw will be equally effective, albeit more time consuming. The joint area itself presents only a minimal increase in frontal area, with core diameter increasing by less than 5 % from 76 to 80 mm. The ergonomics of the joint area can be further enhanced by beveling the blunt ends of the sleeve with a rasp such that they taper to a sharp point at the transition with the core tubes (this is best done prior to fitment of the core tubes into the sleeve). A smear of araldite around this beveled edge will further ensure a smooth profile and unhindered penetration during coring.

Discussion. The coupling technique described here has been used successfully in a diverse range of sediments and often under adverse coring circumstances. The maximum length of tubing that has been joined together is 24 m, comprising four 6 m core tubes and three sleeves. The core was utilized in the southern Cape, at a 'Schwingmoor' or floating bog site called Vankervelsvlei. Having first penetrated through a 1.5 m raft of dense fibrous vegetation, the core extended through 7 m of standing water to the lacustrine sediments below, where vibracoring proceeded to secure an 8 m core before penetration terminated on encountering a compacted clay horizon. In this instance the entire 24 m core was assembled in the field prior to vibracoring and ultimately required the assistance of three support personnel, with guy ropes, to steady the 24 m core tube in the vertical position. It is not, however, a precondition to couple the core tubes in this unwieldy manner. The coupling procedure is equally viable if conducted retrospective to the initial coring event. If coring with a short tube (eg, 6 m) has already commenced and it is then deemed likely that the core could extend beyond 6 m, it is advisable to stop vibracoring on reaching a depth of ± 5 m, at which point there will be a sufficient length (± 1 m) of core tube exposed above the surface to which a second core tube can then be coupled, in the vertical position. Depending on the success of the vibracoring, this process can then be repeated as many times as necessary. In the western and southern Cape, the only limitation imposed on the length of tube that can be coupled together and cored in this manner, appears to be the absence of organogenic sediments deep enough to accommodate long cores. Intriguingly, most boggy sites in the western Cape, and therefore most cores from this region, tend to bottom out in coarse sand or disjointed bedrock at depths ranging between one and eight metres.

More recently, following a bout of renewed optimism by the author, it has become standard practice to begin vibracoring with a 12 m core tube (2 x 6 m, coupled) even in sediments with a known depth of less than 8 m. This approach offers two clear benefits:

i) it is often difficult to regain coring momentum once the vibrations have stopped for more than a few minutes - especially when another tube might need to be coupled. ii) There appears to be a distinct penetration advantage in using longer core tubes to begin with. Where formerly a 6 m core tube might bog down and terminate its penetration at around 5.5 m, a 12 m tube, cored in precisely the same location with the same mechanical advantage, will penetrate to 6.5 m or even 7.0 m (personal observation). Although the additional weight (± 10 kg) of the longer core tube may be a contributing factor, the best explanation for this enigma is offered by Lanesky *et al.* (1979), who report that in a comparative test using 6.5 m and 9.2 m core tubes, a more efficient standing wave (amplitude) is produced in the 9.2 m tube, ultimately improving penetration by up to 40 %. While coring at Verlorenvlei with short (6 m) tubes, it is not uncommon for the tubes to begin to resonate, characteristically, with a progressive increase in pitch as coring proceeds. This phenomenon is particularly evident in sandy sediments where the final metre is the most difficult, if not impossible, to recover. If, however, a longer core tube is utilised, in precisely the same location, coring will proceed at first at the same rate as the shorter core, but will then maintain penetration until a new base level is established, often 1.5 - 2 m deeper. The resonance in the longer tubes is far more subtle. The explanation for this may lie in the proportion of available empty core tube, which acts both as a reservoir and an amplifier for the standing wave. In the short core, as penetration proceeds, so the throttling effect of the surrounding sediment begins to dampen and absorb the vibrations, limiting the amplitude and weakening the penetrating effect at the cutting edge. Simultaneously, the proportion of available empty tube is reduced, and the amplitude of the standing wave declines, resulting in intensifying resonance and a consequent reduction in penetrating power. Put simply, the longer tubes have larger amplifiers (empty tube), and are therefore capable of sustaining a more effective standing wave for longer. This is a useful tip for vibracoring enthusiasts to consider, especially given the potential for a 40 % improvement in penetration.

5.4 Conclusions

The derivation of suitable sample material for palaeoecological research - such as that which forms the subject of this thesis - is critically and fundamentally dependent on a strategic coring programme which is both coherent in its theoretical design and unequivocal in its physical *modus operandi*. In many palaeoecological investigations, considerable, if not integral, emphasis is placed on the interpretation of information obtained from microscopic subsamples of material, which in turn represent subsamples taken from a single core, possibly even from a single site. Given that any inconsistencies

inherent within the procurement technique are likely to be amplified throughout the entire subsampling routine, it is vital that the initial sampling procedure be well resolved and clearly understood. The vibracoring methodology discussed in this chapter has been used extensively by the author in support of this study, and by comparison to alternative methods of core derivation, this technology is considered to represent a significant improvement in both the penetration and recovery of moist unconsolidated sediments, with minimal levels of structural disturbance and, if applied with care, negligible levels of contamination.

Chapter 6

FIELD TECHNIQUES AND SAMPLING STRATEGIES

6.1 Primary sampling strategies applied in the Sandveld

The importance of sensible sampling strategies in palaeoecological studies cannot be overemphasised. In fossil pollen studies, in particular, sampling frequently follows an hierarchical sequence beginning with the primary sampling strategy in the field and thereafter, proceeding via any number of subsampling routines before the final measured aliquot is selected for proportional identification. Despite the fact that the entire theorem of palaeoecological research is intrinsically dependent on the authenticity and reliability of such sampling and subsampling routines (eg, Weinstein-Evron, 1987), most popular textbooks on palaeoecology provide superfluous accounts of physical sampling procedures but gloss over the importance of a well-defined sampling strategy. In defence of field manuals and textbooks, however, there is clearly no substitute for experience in sampling - whether it be primary sampling in the field or secondary subsampling in the laboratory. With hindsight and experience, it is possible to identify a number of potential stumbling blocks that commonly impede judicious sampling the first time around. On the first account, the stratigraphies of fossil deposits tend to exhibit considerable spatial and temporal variation - even within localised depositional environments. Secondly, it is impossible to resolve, by expeditious and affordable means, the absolute chronology of depositional sequences while operating in the field. Absolute dating techniques, such as radiocarbon, are the only reliable methods of determining the depositional and stratigraphic integrity of isolated fossil deposits - yet, these fundamental chronological techniques are costly and require the services of a dedicated, specialist laboratory. Thirdly, until each of the potential subsamples has undergone a series of physical and chemical treatments, their viability in terms of fossil pollen analysis cannot be accurately determined. In some respects, these obstacles tend to engender a 'hit and miss' approach to primary and secondary sampling of fossil deposits. Nonetheless, careful field observations combined with a programme of preliminary sampling can be crucial first steps in the right direction.

A wide range of depositional environments has been sampled from the Sandveld (refer to Figure 3.3 for the respective site locations). Some of these deposits are ideally suited to the vibracoring methodology described in Chapter 5, while others have necessitated alternative methods of sample derivation. Fossil pollen has been sampled

successfully from a vibracore transect across the fluvial-deltaic wetlands of Verlorenvlei (the Grootdrift vibracore transect) and from a single vibracore from an artesian spring deposit (Klaarfontein). Beyond the immediate wetlands of Verlorenvlei, additional sources of fossil pollen have been sampled from two archaeological excavations (Elands Bay Cave and Spring Cave) and from an exposed section in a dune slack depression near Lamberts Bay (Muisbosskerm se Groot Sloot). In support of these palynological investigations, the geomorphological and sedimentological evolution of the Verlorenvlei system have been studied by means of two boreholes drilled at Grootdrift Farm and a vibracore from the Verlorenvlei Cottage embayment. In addition to these predominantly subsurface sampling regimes, recent pollen samples, derived from organogenic surface deposits, have been collected from 19 different locations across the Sandveld, while airborne pollen, collected over a two year period, has been sampled from five distinct vegetation communities near Verlorenvlei.

The remainder of this chapter is dedicated to a brief description of each of the primary sampling strategies employed in the Sandveld. In addition to the relevant technical and physical procedures, consideration is given to the rationale (timing, logic and motivation) behind each sampling strategy. Special attention is drawn to the conceptual and methodological evolution of the study, since this has imposed a particular pattern on the nature and direction of subsequent sampling strategies. Where applicable, significant field observations have been recorded. Descriptions of the stratigraphy and radiocarbon chronology for each site have been reserved for presentation in the detailed results given in Chapter 8.

6.2 Riverine, lacustrine and estuarine deposits

In terms of the basic objectives of the study, the principal sampling focus was to derive sequences of vertically-aligned, depth-correlateable pollen-bearing samples from minimally disturbed and, where possible, highly organic sedimentary deposits. In view of the harsh, semi-arid terrestrial environments prevalent in the Sandveld, the obvious source of such material was considered to be within the depositional precinct of the Verlorenvlei wetlands. Following extensive gouge auger investigations conducted between Redelinghuys and Elands Bay village by the author in 1990, several sites in and around the riverine, lacustrine and estuarine environments of Verlorenvlei were identified as having potential for more detailed investigation. A pilot vibracore, GDV1, derived by the author from the western margin of the wetland, at Grootdrift, in July 1991, led to the initiation of a more substantive geotechnical drilling investigation at this riverine-lacustrine transition.

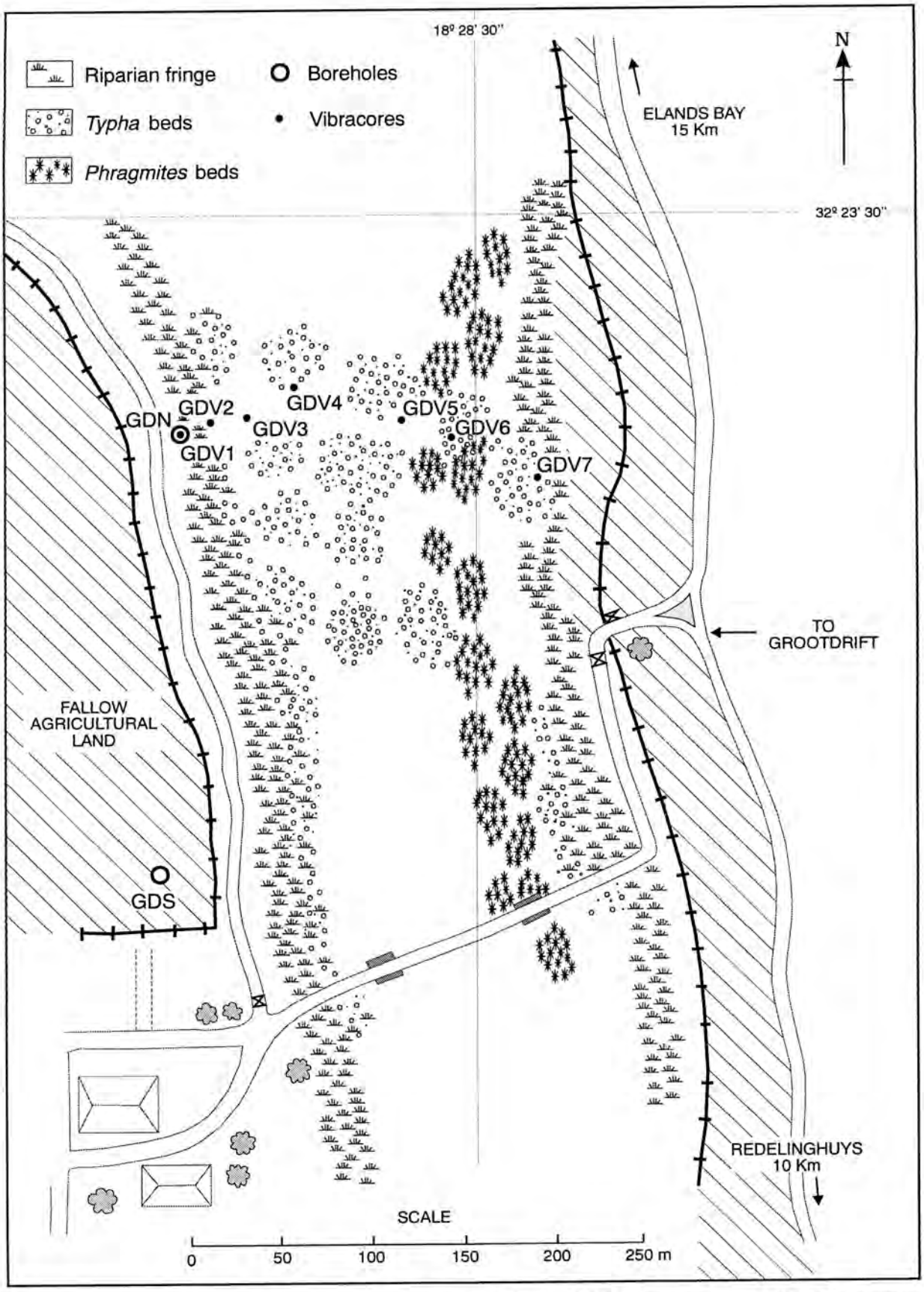


Figure 6.1 Locality map reflecting the position of the boreholes GDS and GDN. The Vibracore transect (GDV1 to GDV7) is plotted according to bearing and scale across the palaeochannel at Grootdrift.

6.2.1 The Grootdrift boreholes

Under the auspices of a collaborative multi-national consortium, a geotechnical investigation proceeded at the farm Grootdrift, in November 1991 (refer to section 5.2 for details of the actual drilling procedure). The scientific investigation was administered by Professor S Horie from the University of Kyoto, Japan, and Associate Professor M Meadows and Professor J Parkington, from the University of Cape Town, South Africa. The drilling programme was coordinated and managed by the author, while the firm Fairbrother Drill Company tendered successfully for the contract. Given the appropriateness of the core material, a wide range of geophysical and palaeoecological techniques was planned, and responsibility for fossil pollen analysis was delegated to the author. The investigation produced two boreholes, GDN and GDS, both derived in close proximity to the western margin of the vlei (Figure 6.1). Precise coordinates of each borehole were established by personnel from the Department of Surveying at the University of Cape Town and these data are presented in Table 6.1.

TRIG. BEACONS	NO.	Y	X	H (amsl)
Muishoekberg	181	53796.88	3581736.10	309.1m
Zandberg	59	42708.31	3573951.42	362.0m
Rooikrans	45	47538.80	3584498.86	291.4m
Kalmberg	168	42920.82	3591067.81	345.6m
Redelinghuys	182	40277.04	3594517.65	353.1m
Wagenpad	56	22445.78	3611786.13	985.9m
BOREHOLES FIXED	**NO.**	**Y**	**X**	**H (amsl)**
GDN	1	49759.89	3585450.98	1.4m
GDS	2	49688.14	3585889.99	4.5m

Table 6.1 Final XY coordinates and heights (above mean sea-level) for the boreholes GDN and GDS.

In order to correspond with the stratigraphy of the pilot vibracore, GDV1, the initial borehole, GDN, was drilled immediately adjacent to the earlier vibracore site (within *circa* 1 m). The location and depositional stratigraphy of GDN and GDV1 are therefore synonymous and they will henceforth be considered as a single entity. GDN is situated, equidistant between the secondary access road to Diepkloof and the western shoreline of the riverine-lacustrine transition, some 400 m downstream from the causeway at Grootdrift (Figure 6.1). A surficial height of 1.4 m above mean sea-level (amsl) has been established for GDN which terminated on reaching disaggregated Table Mountain Sandstone at a depth of 14.6 m. GDS was drilled in the fallow agricultural land some

300 m due south of GDN and some 50 m inland from the access road. This location was elevated by 4.5 m (amsl) and the hole reached a depth of almost 26 m. Sediment cores from both of these boreholes, entrained within PVC core liners, were collected by the author and delivered to the Palaeoecology Laboratory of the Department of Environmental and Geographical Science at the University of Cape Town.

6.2.2 The Grootdrift vibracore transect

Against the background of poor core recovery and possible sedimentary disturbance associated with the geotechnical drilling investigation that produced the boreholes GDN and GDS, it was apparent that further sampling, in pursuit of suitable, undisturbed pollen-bearing sediments, would have to depend on further vibracoring investigations. Encouraged by the stratigraphic knowledge gained from GDV1 (and GDN), the author elected to run a transect of cores across the fluvial delta which presently describes the transitional riverine-lacustrine geomorphology at Grootdrift. Vibracoring commenced in March 1992 and proceeded over a period of several days. Using the location of GDV1 as a benchmark, six additional vibracores, each ranging in depth from 4 - 6 m, were extracted from across the wetland. At the time of coring, the technique needed to join the lightweight aluminium tubes together had yet to be developed (refer to section 5.3.5 for details of this new technique). Core depth was therefore constrained by the 6 m length of available tubing, except in the case of the shore-based cores, where more consolidated basal sediments appeared to be the limiting factor in terms of penetration.

VIBRACORE	DISTANCE FROM GDV1	BEARING FROM GDV1	H (amsl)
GDV2	19.48 m	13° 26' 00'	0.70 m
GDV3	51.07 m	20° 33' 00'	-0.39 m
GDV4	90.03 m	07° 39' 00'	0.72 m
GDV5	174.04 m	27° 21' 00'	0.81 m
GDV6	211.37 m	30° 31' 00'	0.69 m
GDV7	282.07 m	38° 47' 00'	1.82 m

Table 6.2 Summary data of the spatial distribution of the Grootdrift vibracores relative to the fixed borehole GDN / GDV1.

The application of an electronic theodolite (instrument model: Wild TC 1000) allowed the author to fix the spatial and altitudinal position of each vibracore relative to the existing datum that the UCT surveyors had provided for borehole GDN/ GDV1. Given the present constraints imposed by the US military on the precision of Global Positioning

Systems (GPS), exact coordinates of each core have not been calculated, since they are not considered to be of any use in relocating individual cores within the transect. Instead, the precise horizontal distance and bearing relative to GDN/ GDV1, together with the height (amsl), have been recorded (Table 6.2).

Reference to the scale diagram, Figure 6.1, reveals that the distribution of the vibracores is skewed somewhat in favour of the western shore and extends northwards in a gentle arc before curving back towards the eastern shore. This aberration in the coring profile is the result of extremely challenging working conditions among the reed beds. At the time of coring, the carcass of a trapped and decaying cow bore testimony to the perils of the glutinous mud, while standing ponds up to 2 m deep required that the equipment be rafted and manipulated from one perched *Typha* bed to the next. Despite these fieldwork hazards, the operation satisfied the original sampling requirements in every respect.

The Grootdrift vibracore transect adopts a logical numbering sequence across the vlei from GDV1 (1.4 m amsl) on the western fringe, to GDV7 (1.8 m amsl) on the steeper-sloping eastern fringe. GDV2 and GDV6 are located, at similar elevations, on opposite sides of the vlei and delineate the transition between the riparian vegetation on the respective banks and the *Typha* beds within the wetland. With corresponding heights of 0.7 m (amsl), GDV2 and GDV6 thus indicate the contemporary low-water mark to be around this level. GDV3 (-0.4 m amsl) was cored from beneath 1.1 m of standing water in a pond among the reed beds near the western shore. This small embayment was initially thought to represent part of a former river channel and this supposition provided the impetus for a core at this location. However, subsequent discussion with the local farmer, P van Zyl, revealed that the pond has, for many years, been frequented by livestock and that the present open water persists as a remnant of a former much larger embayment that prevailed during the earlier part of this century. It would seem therefore that cattle have maintained the pond in an effort to graze among the young reeds and *Myriophyllum* - just as they do elsewhere in the open water today. Both GDV4 (0.7 m amsl) and GDV5 (0.8 m amsl) were derived from the extensive, almost impenetrable *Typha* beds which dominate the middle of the Grootdrift transect. Following extraction, all the cores were sealed with airtight rubber stoppers and transported intact to UCT where cutting, subsampling and further analyses proceeded under laboratory conditions.

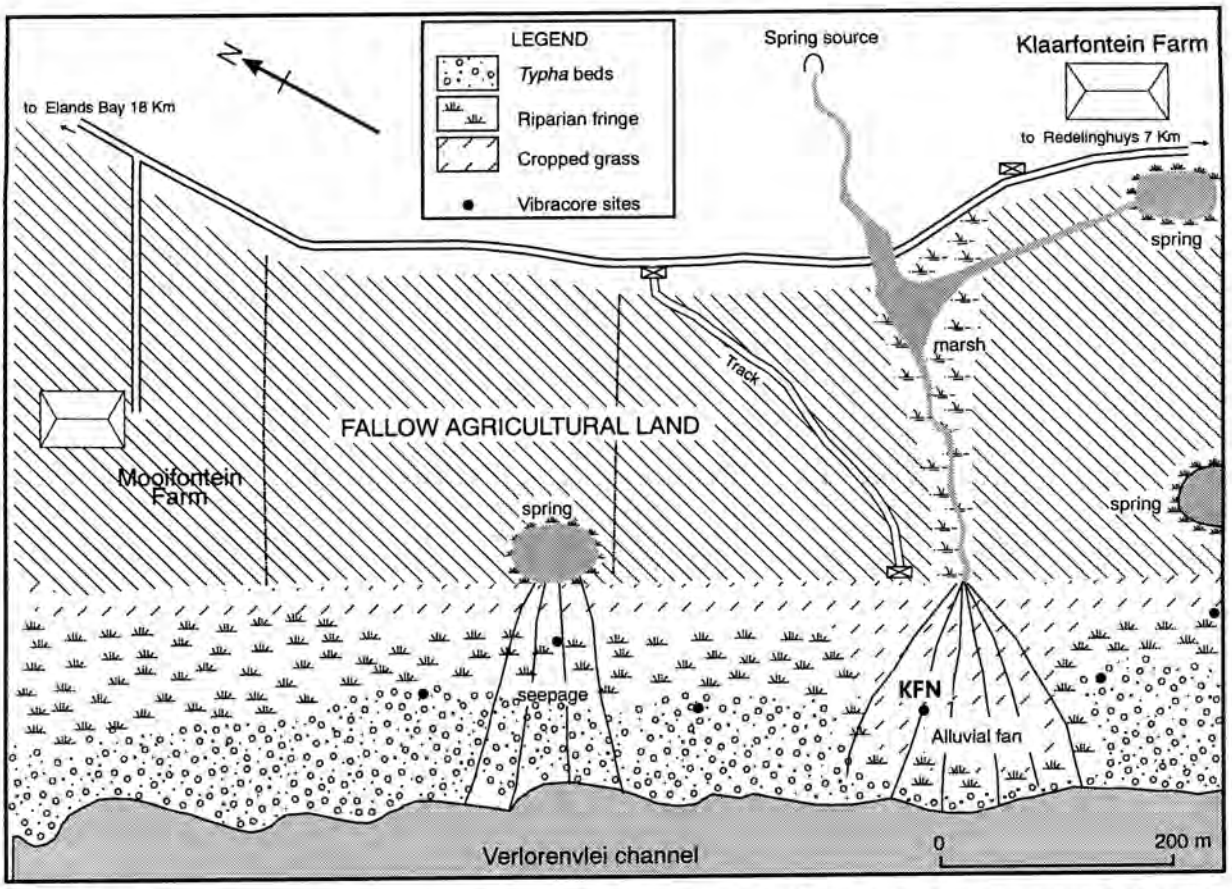


Figure 6.2 Locality map of the Klaarfontein vibracore sites. The vibracore KFN was derived from the colluvial-alluvial fan which radiates towards the open water of Verlorenvlei.

6.2.3 Klaarfontein Spring site

The motivation to core at Klaarfontein was prompted primarily as a result of a depositional aberration at Grootdrift. The radiocarbon chronology that followed from the Grootdrift transect revealed that a significant depositional irregularity had occurred at the site, and that a substantial part of the mid-late Holocene sedimentary record (*circa* 3 600 to 600 years BP) is absent from Grootdrift. In consideration of the sensitivity of this particular time period in terms of elucidating former environmental conditions at Verlorenvlei, a search was made for a more complete sedimentary record. In this regard it was hoped that the artesian springs, located on the neighbouring farm Klaarfontein, would offer a similar depositional environment to that of Grootdrift, yet without the conundrums imposed by the complicated erosional dynamics anticipated for the Verlorenvlei riverine/lacustrine/estuarine environment. Coring commenced at Klaarfontein in November 1992 in the vicinity of the boggy colluvial-alluvial fan produced by the spring, marsh and stream environment. In an effort to pinpoint the most appropriate sampling location, a series of four vibracores was extracted from the bog, the contents of which were then vibrated out in the field to allow for an immediate *in situ*

inspection of the core material. On the basis of this reconnaissance work, a single core of 6 m was derived from the distal lobe of the alluvial fan that radiates towards the eastern shore of the Verlorenvlei proper (Figure 6.2). The Klaarfontein core site, denoted as KFN, is perched above the modern high water level of the Verlorenvlei, some 50 m inland from the eastern shore, at an elevation of 1.9 m amsl (established by theodolite instrumentation). Coring was again constrained by the 6 m length of available core tube, although more recent efforts by the author to gain additional material from the same site suggests that unconsolidated sediments terminate at around 8 m beneath the modern surface. Although the Klaarfontein core would later reveal a more complete Holocene record than the cores from Grootdrift, this site also appears to have experienced a depositional hiatus sometime between 1 900 to 300 years BP.

6.2.4 Verlorenvlei Cottage core

In addition to the derivation of pollen-bearing samples from the upper reaches of the Verlorenvlei wetlands, various cores from both the upper and lower reaches of the Verlorenvlei system have been investigated for their sedimentological record. The boreholes GDN and GDS provide a reasonably coherent late Quaternary sedimentary record from Grootdrift, while the Verlorenvlei Cottage core provides valuable information, for the same time period, on the palaeogeography, sedimentology and estuarine dynamics of the lower system. In March 1991 an investigative vibracore was obtained from the shelly lacustrine deposits opposite the quarry on Verlorenvlei Farm (Figure 6.3). The 3 m core revealed the presence of an 80 cm layer of densely packed marine shells, capped at the surface by approximately 1 m of sandy mud. The shell layer is consistent with other exposed deposits within the vicinity and is believed to be reworked material of late Pleistocene origin (D Miller, personal communication). No further analyses have been conducted on this core. In May 1994, in an effort to resolve the spatial and temporal dimensions of the depositional hiatus reflected in the Grootdrift vibracores, a second core was obtained from the Verlorenvlei Farm embayment. Located directly due north of the research cottage on the Verlorenvlei Farm, the core was secured from within the reed beds which flag the presence of mudbanks some 200 m beyond the first open water channels. Following the long dry summer of 1993/94, water levels within the vlei were extremely low and this allowed for the heavy equipment to be portaged through the shallow water to the relative security of the central reed beds. In anticipation of deeper deposits in the lower reaches of the system, two 5 m lengths of tubing were joined in the field prior to the exercise. Coring proceeded to an effective depth of 8.2 m (producing 7 m of core material) before penetration ceased

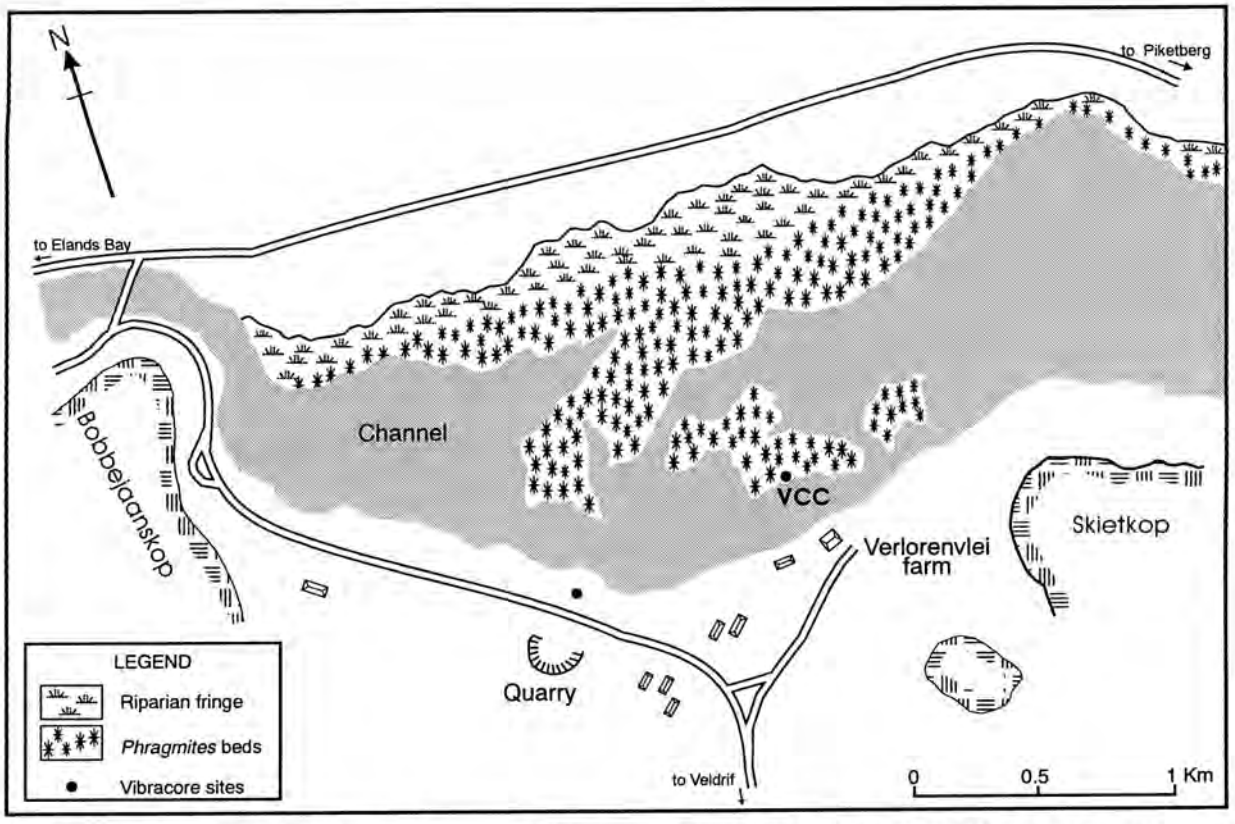


Figure 6.3 Location of the Verlorenvlei Cottage core (VCC) among the reed beds of the Verlorenvlei Farm embayment.

abruptly at what is believed to be a compacted shell horizon. On extraction, the core revealed a damaged leading edge and missing core catcher, yet no sediments appeared to have been lost as a consequence. The elevation of the Verlorenvlei Cottage core has yet to be accurately established by instrumentation techniques. This objective has proved to be difficult in the face of high water levels that have persisted since the coring date. However, at the time of coring, the water level, relative to the core, indicated a height exactly 20 cm lower than that recorded from the location of GDV2, at Grootdrift, for the same time period. On these grounds, an elevation in the order of 0.5 m amsl would seem highly probable for the Verlorenvlei Cottage core. As with the Grootdrift and Klaarfontein cores, the Verlorenvlei Cottage core was sealed by means of airtight stoppers and returned, unopened, to the laboratory at UCT, for further analysis.

6.3 Archaeological sites and exposed sections

Archaeological cave deposits are a well documented, sometimes vital source of fossil pollen in arid environments (Horowitz, 1992). With respect to the complexities of the archaeological record interpreted for the Sandveld during the Holocene, a number of critical expositions regarding landscape and subsistence changes have arisen as a product of cave site investigations (Parkington, 1986). Reaffirming patterns concerning the nature and timing of human occupation at certain cave sites in the Sandveld, indicate the absence of people from the distal regions of Verlorenvlei during the period 8 000 to 4 000 BP. There is mounting proxy (archaeological) evidence in support of unfavourable climatic and environmental conditions in the Sandveld coincident with this time period. However, the occupational hiatus (of certain prominent cave sites) in the Sandveld, as a consequence of broad-scale environmental deterioration, has yet to be tested against the fossil pollen record. In an effort to explore the hypothesis of environmental perturbations as the principal agent in determining the presence or absence of humans from parts of the Sandveld during the Holocene, the decision was taken to investigate the pollen record from Spring Cave and later, Elands Bay Cave, both near Verlorenvlei. A third site, Muisbosskerm se Groot Sloot, although not an archaeological site *per se*, is juxtaposed in close proximity to the Steenboksfontein Cave complex and some of the large archaeological 'mega-midden' shellfish deposits that are to be found along the coastal dune cordon to the south of Lamberts Bay (Parkington, 1986). An additional advantage of sampling from these predominantly terrestrial sites is that their pollen record is expected to reflect an unobstructed terrestrial signal - unlike the wetland sites, where pollen from the local vlei vegetation appears to have masked the terrestrial signal.

6.3.1 Muisbosskerm se Groot Sloot

In June 1993, a suitable section of the exposed trench on the farm Muisbosskerm was designated for sampling purposes and the exact location (32° 08' 28.74' S; 18° 18' 32.68' E) was secured by means of a GPS (Magellan Nav 5000 Pro Global Positioning System). A shovel and assorted trowels were used to clear an approximate vertical face on the eastern side of the trench, following which the stratigraphy was measured, described and logged (these details, together with the chronology, from part of the results in Chapter 8). Morphological properties including the shape, texture and estimated composition of each horizon were detailed in a scale diagram. The respective soil colours were measured and recorded using a Munsell Soil Colour Chart (1975).

Sampling proceeded along two lines. Firstly, four large bulk sediment samples were derived, at measured intervals, from within the fibrous peaty deposit at the base of the excavation. Any number of these bulk samples were to be used, if necessary, for radiocarbon dating. As such, care was taken to ensure that a sterile sampling instrument was employed during each sampling event. Tough, sealable plastic bags were used as receptacles for the bulk samples and these were labeled accordingly. The second set of samples was derived for the purposes of pollen analysis. Sampling commenced at the base of the excavation, which corresponded roughly with the water table at the time of sampling, and proceeded to surface level. Plastic vials, measuring 8 cm in length, with a diameter of 2.5 cm, were forced into the section at regular intervals. Particular attention was given to sampling closely on either side of significant stratigraphic boundaries. Each vial was forced into the deposit, twisted, carefully extracted, sealed with a lid and labeled with a corresponding depth value. In total, 28 samples were recovered from 1.75 m of exposed deposit. In an effort to resolve the nature and composition of the subsurface sediments, concealed beneath the base of the waterlogged excavation, a gouge auger was used to sample an additional 50 cm of deposit from below the watertable. Four subsamples from the augered core were collected for pollen analysis. By virtue of the length (> 400 m) of the exposed trench at Muisbosskerm, two important observations could be made on the basis of a spatial assessment of the entire exposed stratigraphy. Firstly, given the nature of the fibrous organic peat, which occurs consistently between 117 - 175 cm below the surface, the site appears to have been much moister at some period in the past, possibly supporting fresh water and riparian vegetation. Typically, such a scenario would describe a coastal dune slack depression where abundant fresh water accumulates, and remains perched above the denser hypersaline watertable. Following this period of organic sedimentation, the site then appears to have dried progressively, while well-sorted, probably reworked marine sands appear to become the dominant depositional facies. On the basis of the stratigraphy, it was hoped that the Muisbosskerm sequence would provide a continuous record of sedimentation since at least the mid-late Holocene and that the site, owing to its terrestrial disposition, might be free of the problematic sedimentary discontinuities prevalent within the Verlorenvlei wetlands. The second important observation that could be made on the basis of the extensive trench exposure was the presence of a distinct sequence of ploughing horizons down to a level of 45 cm from the present surface. Since the trench bisects a fallow field of winter wheat, the depth and variation within the ploughing profile would seem entirely consistent with the deep ploughing techniques commonly employed in the Sandveld today. As a consequence of this latter observation, interpretation of the uppermost pollen samples from Muisbosskerm will need to be considered in the context of massive disturbance and possible repeated inversions of the soil profile.

6.3.2 Spring Cave

Following preliminary investigations of the fossil pollen from Grootdrift and Klaarfontein, it became clear that these two wetland receptacles, were exhibiting a strong collectional and preservational bias in favour of pollen produced by local (wetland) plant communities. In an effort to circumvent the masking effect of local pollen over both regional and, more specifically, pollen derived from terrestrial vegetation communities, alternative depositional environments were sought for investigation. The harsh nature of the Sandveld environment does not lend itself to the accumulation and preservation of organic material beyond the limits of the aquatic environment, and the only alternative sources of fossil pollen-bearing deposits appear to be those associated with archaeological accumulations. Following close cooperation with the Department of Archaeology at UCT, preparations were made to revisit the existing excavation at Spring Cave shelter, for the purposes of fossil pollen sampling. Of the many potential cave deposits near Elands Bay, Spring Cave is one of the few that lends itself readily to palynological investigation. The site has developed in response to a water seep at the rear of the cave and, along with human occupation, this has undoubtedly contributed to the accumulation of organic sediments. Furthermore, the partial excavation is well dated and appears to represent a reasonably coherent sequence of accumulation since the mid-Holocene. Most importantly, however, the sampling procedure was planned to coincide with further archaeological excavation of a previously exposed section within the site. In turn, this presented an expedient opportunity to derive fossil pollen samples from an *in situ* context from Spring Cave . In April 1993, under the supervision of R Yates, the *sondage* I9 (a test sounding measuring 1 m x 1 m across) was uncovered and the section face denoted as I9/H9 was prepared for sampling. I9 is located in the centre of the northern half of the cave, towards the front of the shelter (Figure 6.4). The seepage pool is located towards the rear of the shelter and recessed centrally within the southern half of the cave. A gouge auger was used to sample the damp deposits that have formed towards the front of the cave in response to drainage from the seepage pool (Figure 6.4). Owing to the lack of stratigraphic continuity between the augered sample and the chronologically secured I9 section, some 10.4 m distant, the seepage deposits have not been investigated further. Instead, 11 pollen samples were collected from the I9/H9 section face, by means of the vial procedure employed at Muisbosskerm. Certain advantages may be gained from sampling an exposed archaeological section, as opposed to an augered profile. Firstly, the investigator can chose the precise location of each sample from a broad vertical and horizontal plane, and secondly, the provenance of each sample can be accurately recorded within the three-dimensional excavation matrix. In turn, the samples can be

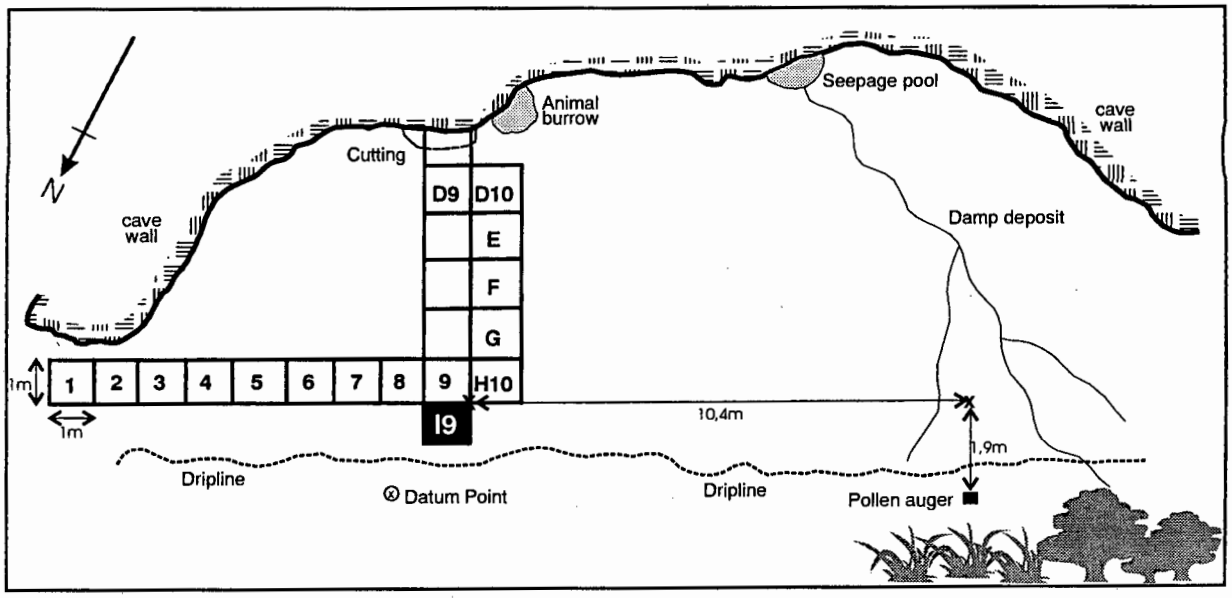


Figure 6.4 A floor plan of Spring Cave. The excavation unit I9 is highlighted towards the entrance of the cave.

related to other fossils such as charcoal and macroscopic plant remains. Sampling proceeded from the bottom up, with the basal sample being collected immediately above bedrock at 107 cm, and subsequent samples, from within the set of distinct stratigraphic horizons that describe the overlying deposit at this location. The uppermost sample was taken at 25 cm depth in what is believed to be the final occupation layer (R Yates, personal communication). Sediment integrity above this level is uncertain. Sampling was complicated by the presence of shell within the deposit which, in some cases, obstructed the passage of sediment into the vials. Under these circumstances, the sediment matrix had to be manipulated into the vials by means of a clean spatula. Finally, a bulk sediment sample was obtained from the base of the excavation and packaged in accordance with the requirements for radiocarbon dating. On completion of the sampling procedure, the excavation was carefully resealed with durable plastic sheeting and backfilled with pre-sorted deposit so as to mitigate against unwarranted erosion or vandalism of the exposure.

6.3.3 Elands Bay Cave

Since the late 1960's, archaeologists have been researching the human-cultural and palaeontological record preserved among the stratified deposits of Elands Bay Cave. Former occupation, albeit sometimes incidental, has spanned the period since the Last Interglacial to the present day. Interpretation of the cultural debris and associated fossil sequence preserved within this important site, has allowed for the evolution of a

fascinating prehistoric record (Parkington, 1981; 1986). More recent efforts by Parkington *et al.* (1988) have centred on an improved understanding of palaeoenvironments and their role in determining the spatial and temporal patterns of former human occupation along the Sandveld coast. Given the conspicuous absence of natural organic accumulations dating to the Last Glacial Maximum from anywhere in the Sandveld, or indeed the southwestern Cape (Meadows, 1988a,b; Harwood,1994), the chance to examine fossil pollen from this time period, albeit from an archaeological deposit, has proved to be an overwhelming academic incentive.

With the cooperation of Professor J Parkington and with the assistance of N Erlank, both from the Department of Archaeology at UCT, selected archival sediments from former excavations at Elands Bay Cave were subsampled for analysis of their fossil pollen content. Despite extremely poor preservation in one of the two initial test samples considered, the author agreed to proceed with the analysis of 19 additional samples from assorted levels in the Elands Bay Cave sequence. All of these subsamples were derived from larger archival bulk samples, most of which date back to deep sounding excavations at Elands Bay Cave (Table 6.3).

SAMPLE NUMBER	LENS NAME	LAYER NUMBER	SAMPLE COLUMN	DEPTH (cm)	COLLECT DATE	CHARCOAL MASS (g)
DMS 21	LIME	22	UNRECORDED	UNRECORDED	OCT 1979	0.5
DMS 71	BSBP SPIT1	12	BULK SAMPLE	UNRECORDED	DEC 1970	21.3
DMS 86	SPINKS	21	W	6-8	NOV 1980	0.7
DMS 87	SPINKS	21	W	8-14	NOV 1980	2.4
DMS 88	KALLIE	22	W	14-18	NOV 1980	1.3
DMS 119	LIME	22	E/N	25-30	NOV 1980	2.7
DMS 120	SPALL	23	E/N	30-37	NOV 1980	2.7
DMS 121	GERRIE	23	E/N	37-44	NOV 1980	3.5
DMS 122	TAP TAP	23	E/N	44-50	NOV 1980	5.5
DMS 123	PATTERSON	23	E/N	50-60	NOV 1980	5.9
DMS 138	SMOKE	13	C1	UNRECORDED	NOV 1980	1.6
DMS 140	DUST	13	C1	UNRECORDED	NOV 1980	0.4
DMS 141	ASHES	13	C1	UNRECORDED	NOV 1980	0.8
DMS 142	GBS 1	16	C1	UNRECORDED	NOV 1980	1.0
DMS 144	GBS 2	17	C1	UNRECORDED	NOV 1980	0.4
DMS 146	GBS 1	16	C2	UNRECORDED	NOV 1980	0.2
DMS 147	GBS 2	17	C2	UNRECORDED	NOV 1980	1.0
DMS 149	OBS 1	18	C2	UNRECORDED	NOV 1980	--
DMS 150	OBS 2	19	C2	UNRECORDED	NOV 1980	--

Table 6.3 Excavation data from Elands Bay Cave. Sample numbers correspond with selected bulk units used for fossil pollen analysis.

6.4 Sampling strategies for contemporary pollen

As this study represents the first of its kind in the Sandveld, there exists no information regarding modern pollen assemblages exists for the region. In fact, one of the most imposing constraints on fossil pollen studies in many areas of southern Africa, may be attributed to the paucity of contemporary pollen data for the sub-continent. Considering the enormous plant diversity among the ecotonal Sandveld environments, and given the absence of any form of contemporary pollen studies, accurate interpretation of the fossil pollen spectra from this region is likely to be handicapped. In an effort to establish modern pollen data from identifiable (analogue) vegetation communities in the Sandveld, the author was compelled to devise a strategy to sample modern pollen spectra.

Two different sampling techniques have been employed in the collection of modern pollen. The first involves the seasonal trapping of airborne pollen in specially constructed pollen traps. The second approach concerns itself with the collection of recent, superficial sediments and soil samples, in the anticipation that these will exhibit a complimentary, perhaps more comprehensive record of recent pollen. The specifics of both techniques are discussed below.

6.4.1 Airborne pollen

Based on the relative success of airborne pollen sampling strategies adopted by Meadows and Meadows (1988) in the Winterberg mountains of the eastern Cape and Sugden (1989) in the Cederberg mountains of the western Cape, it was considered prudent to follow the same procedure in the Sandveld. The technique is contingent on the use of a pollen trap modified after the design of Flenley (1973) and Cundill (1986) and similar to that described by Bush (1992). The trap comprises a simple plastic funnel, of the domestic variety, which is then modified as follows. A suitable filter paper and fine gauze combination (to allow the passage of rain water through the funnel but sufficiently fine to trap pollen grains) is glued into the neck region of the funnel. A wad of acetate fibre is then teased apart to form a dense mound of haphazard fibres which are then compressed into the tapered region of the funnel. The acetate fibre is held in place by a wire-mesh screen that is fastened over the top of the funnel opening. The principle behind the trap is that pollen rain will come to settle on the funnel exposure, as it does

naturally in the landscape, and that transient pollen will consequently become trapped in the elaborate mesh of acetate fibres.

In June 1990, 11 such traps were deployed in five distinct vegetation communities in and around Verlorenvlei (refer to Figure 3.3). Two traps, one at ground level, the other attached to a 1 m high fence-stake, were located among the wetlands near Redelinghuys. Two traps were placed in similar fashion, among the restioid Strandveld north of the Lamberts Bay road, near Kliphoutkop. Two traps were secured among the rocky fynbos slopes towards the summit of Uitkykberg and a further two were placed in the strandveld above the southern shore of the embayment near Verlorenvlei Farm. A single trap was attached to the trunk of a *Podocarpus elongatus* specimen in a small thicket near Diepkloof Cave and another single trap was placed among the coastal scrub on Bobbejaansberg. The final trap was placed in the middle of a *Phragmites* thicket along the vlei margin on the farm Bontheuwel. Where possible, the traps were serviced (acetate fibre was collected and replaced) at approximately four-monthly intervals for the following two years. By April 1993 it had become apparent that the traps were failing in their role as collectors of modern pollen and the decision was taken to discontinue the monitoring programme. For the most part, the traps appear to have held an irresistible attraction for indigenous wildlife. During times of inspection, a number of the mountain-located traps were found to have been destroyed by baboons. Vandalism also appears to have played a role in the repeated theft of the Redelinghuys pair, although it is more likely that primates of the human variety were responsible in this instance. A universal problem was the apparent desirability of the acetate fibre for nest building purposes. Despite the fine wire-mesh screen, birds, including crows, persisted, and in many cases succeeded, in their efforts to collect the acetate fibre by extracting it through the wire-mesh. Although some acetate fibre was collected from the traps, the pollen content was disappointingly low and poorly preserved. It is speculated that the extreme summer temperatures, strong solar radiation and frequent dry winds may have accelerated the oxidation process in advance of the laboratory assessment.

6.4.2 Recent sediments

Given the complications attached to the sampling of airborne pollen in the Sandveld, it was considered that a more appropriate reflection of the modern pollen rain dynamics might be contained within recent surficial sediments. In some respects - provided the modernity of the pollen contained among surficial sediments can be guaranteed - there may be certain advantages in sampling recent sediments for modern pollen. If it is

considered that modern pollen spectra are to be used as an interpretative tool in the elucidation of former vegetation identities, based on their fossil pollen record, it makes sense to sample the modern pollen from a similar depositional context as that of the fossil pollen. In other words, surficial sediments are likely to have imposed similar differentials, in terms of pollen deposition and pollen preservation, as those encountered in the fossil deposit. Ultimately, this should ensure a more realistic modern analogue for interpretative purposes than airborne pollen which has not endured the same degree of collectional, depositional or preservational bias.

NO	LOCATION	DESCRIPTION
1	Piketberg uplands	Mature Dry Mountain Fynbos on Piketberg including stands of *Leucadendron*, *Protea* and *Passerina* spp.
2	Bloubak se koppe	Pristine Dry Mountain Fynbos among rocky mountain slopes. Including *Olea*, *Maytenus* and *Rhus* spp.
3	Bloukop grove	Afromontane Scrub Forest among the gullies on Uitkykberg, including *Podocarpus elongatus* and *Olea*.
4	Grootdrift Farm	Degraded (overgrazed) Dry Mountain Fynbos among rocky slopes above western margin of Verlorenvlei.
5	Uithoek	Restioid Lowland Fynbos among rolling hills opposite Staanklipbult. Abundant *Willdenowia* spp.
6	Rooikrans koppie	Restioid Strandveld on the eastern slopes above Grootdrift. Abundant restios and *Euphorbia* spp.
7	Diepkloof Farm	Heavily grazed Strandveld/ fynbos vegetation on the slopes below Diepkloof Cave near large *Ficus* specimen.
8	Diepkloof Cave	Admix of Karroid Strandveld, fynbos and Scrub Forest near Diepkloof Cave. *Rhus*, *Crassula* and *Olea* spp.
9	Muishoekberg	Degraded Karroid Strandveld. Dominated by unpalatable spp. eg, *Euphorbia* & *Crassula*.
10	Redelinghuys wetland	Riparian vegetatiom along the western margin of the Redelinghuys wetland among dried out *Typha* beds.
11	Klaarfontein Spring	Damp (disturbed) organic deposit near source of spring. Sedges, grasses, Arum lilies and ruderal weeds.
12	Muishoek fringe	Shrubby Strandveld above the *Phragmites* skirt along westen shore of Verlorenvlei embayment.
13	Grootdrift coring site	Surface muds sampled among dense reed beds of the transitional wetland. *Typha*, *Phragmites*, *Juncus* spp.
14	Verlorenvlei embayment	Coastal Strandveld near the main Verlorenvlei embayment. *Juncus*, *Cyperus*, *Crassula*, *Lampranthus* spp
15	Muisbosskerm	Straggling Coastal Strandveld among primary dune cordon. Asteraceous shrubs dominate.
16	Spring Cave	Sample collected from damp profile in front of water seep. *Oxalis*, Restios and ferns.
17	Verlorenvlei mouth	Saline-tolerant vegetation on seaward side of causeway at Elands Bay. *Spartina*, *Salicornia*, *Juncus* spp.
18	Wadrifsoutpan	Extensive saltmarsh and hypersaline pond along the coast. *Spartina*, *Salicornia* and *Chenolea* spp. dominate.
19	Boekpenskop	Scattered hyracium middens.

Table 6.4 The location, description and typical vegetation of 19 selected surface sites in the Sandveld. The sites have been selected from along an environmental gradient which covers the area from Piketberg in the east, to Wadrifsoutpan along the West Coast.

Surficial samples have been collected from 19 distinct phytogeographical locations in the Sandveld. Selected from along an altitudinal and moisture gradient extending from the eastern margin of the Sandveld at Piketberg, to the West Coast margin at

Wadrifsoutpan, the complete range of modern Sandveld vegetation communities has been sampled (refer to Figure 3.3). The sampling procedure is elementary and involves the collection of approximately 200 g of the top layer (1 - 2 cm) of organic detritus incorporated within the surficial sediment. In the absence of organic detritus, the sediment surface itself was sampled. Horowitz (1992) highlights some of the potential pitfalls of sampling recent deposits from arid environments, including the problem of reworked surface material - especially among aeolian environments. As far as possible, actively eroding and depositing surfaces, including dunes and dongas, steep slopes, water courses and deflation hollows have been avoided in favour of more stable, sheltered, vegetated surfaces. Table 6.4 provides a brief summary of the sampling details, including locations and a brief description of the vegetation content.

6.5 Conclusions

The description of the primary sampling procedures, outlined in the sections above, should provide the reader with an indication of the complexities of sampling among marginal organic deposits in a dynamic physical environment. The strategy has developed sequentially, through time, in response to a logical framework that has endeavoured, where possible, to remain faithful to the original sampling criteria as set out in the introduction of this thesis. In view of the depositional hiatuses at Grootdrift and Klaarfontein, attention has shifted away from the Verlorenvlei wetlands in search of new and alternative organogenic deposits. In so doing, the opportunity to investigate archaeological deposits has brought with it a new set of palaeoecological questions and an additional focus for the study. In essence therefore, the study has not allowed itself to be constrained by a rigid, predetermined sampling framework, but has, as a consequence of necessity, evolved in response to new opportunities.

Chapter 7

LABORATORY TECHNIQUES AND DATA PRESENTATION

7.1 Introduction

The basic aim of fossil pollen analysis is to reconstruct the vegetation history for a chosen area for a certain period of time. In this case, the study sites are located in the Sandveld and radiocarbon dates reveal that the sequences range in age from the early Holocene to the last few hundred years. In previous Chapters, it was demonstrated that, although the basic principles which govern the technique of pollen analysis are ecologically sound, there are a number of overriding factors that can lead to misinterpretation of the fossil pollen record. Among these problems, the differential production, dispersal and preservation of pollen were cited as potential, and often unavoidable, contributors to representative bias. A second set of potential methodological problems was attributed to the actual palaeoecological investigation, including; sample preparation, pollen identification, statistical treatment, chronological techniques and palaeoenvironmental interpretation. Of these, the first two are considered to pose the most challenging obstacles to the methodological skills and resourcefulness of the analyst. As in most pursuits, there is seldom any substitute for the experience gained as a consequence of trial, error and repeated experimentation. In practice the size, duration and nature of this study have allowed for the progressive evolution of the scientific methodology. The sections which follow detail the various methods employed by the author in: i) the preparation of modern pollen for reference slides, ii) the preparation of fossil pollen for comparative identification and counting, and, iii) the statistical treatment of the data for analysis, comparison and presentation. It is assumed that the reader will be familiar with basic techniques in pollen preparation and also with general laboratory etiquette. A review of these techniques is not provided since they are comprehensively synthesised in introductory texts such as Fægri *et al.* (1989) and Moore *et al.* (1991).

7.2 Reference collection of West Coast Pollen

Quaternary pollen analysis is integrally dependent on modern collections of known pollen types for the comparison and identification of the fossil grains (Moore, *et al.*, 1991). It is implicit, therefore, that the greater the level of taxonomic resolution achieved for the

fossil pollen record, the greater will be the value attached to the palaeoecological interpretation thereof. Ideally, resolutions should be made to the lowest possible taxonomic rank, that of species level. However, owing to morphological complexities among the Sandveld pollen taxa, this degree of taxonomic resolution has seldom been achievable and, for the most part, the identification of fossil pollen has been made at the genus or family level.

Arguably the greatest obstacle in the analysis of fossil pollen from southern Africa is the paucity of adequate reference collections and pollen atlases to aid in the identification of fossil pollen grains. The situation is compounded by the enormous regional variability inherent among the southern African flora, and the high degree of species diversity, estimated at 21 350 species for the subcontinent and almost 8 500 from the Cape Floristic Region alone (Bond and Goldblatt, 1984). Van Zinderen Bakker (1953; 1955) and van Zinderen Bakker and Coetzee (1959) were the first to produce introductory pollen atlases for southern Africa but these have proved to be of little benefit to studies conducted in the fynbos biome (Sugden, 1989). In the absence of a single comprehensive pollen reference collection for the flora of southern Africa, various regional collections have come to be assembled. One such collection, the Cape Town Collection of Pollen (CTCP) was initiated by J Sugden in 1985 and is presently under the curatorship of the University of Cape Town. The CTCP comprises a total of 3 500 microscope slides and 1 500 reference photographs and includes a representative range of species from across the Karoo and fynbos biomes. Sugden (1989) has demonstrated the usefulness of this collection in the identification of fossil pollen from Karoo and fynbos sites, but it is recognised that the collection will need to be augmented for studies outside of these specific areas. Although the CTCP includes species from the Tanqua Karoo and the western Cape mountains, it was clear that the collection was under-represented with respect to pollen from the lowlands of the West Coast Sandveld.

7.2.1 Compilation of herbarium pollen

A thorough description of the composition of Sandveld vegetation is presented in Mason (1972) and Bond and Goldblatt (1984), while Sinclair *et al.* (1986) and Grindley and Grindley (1987) provide comprehensive species lists for the Verlorenvlei region. These data were used to supplement Sandveld species lists supplied by the National Botanical Institute (NBI) at Kirstenbosch, while frequent site visits to Verlorenvlei, often in the company of specialists willing to share their botanical expertise, proved to be an invaluable source of additional information regarding the composition of Sandveld

vegetation. From this information, a select list of Sandveld-specific taxa, comprising 250 species, 139 genera and 64 families was compiled by the author for the purposes of inclusion in the CTCP. Pollen specimens were obtained from the Bolus Herbarium at the University of Cape Town and from limited collections made in the field. Extreme care was required during the sampling of herbarium pollen and, in each case, the specimen sheet was amended to acknowledge the contribution made to the CTCP. The full list of West Coast Pollen (WCP), now integrated into the CTCP, is available from the University of Cape Town. For convenience and consistency, the WCP samples have been labeled according to family, genus and species name, and carry the Gibbs Russell (1984) species number which corresponds to the catalogue system most widely in use in South African herbaria.

7.2.2 Laboratory techniques for reference pollen

Given that identifications of fossil pollen are to be based on morphometric comparisons drawn between the pollen from modern taxa, the preparation of modern pollen for inclusion in reference collections should approximate the techniques employed in the preparation of fossil material. As a consequence of diagenesis during burial, fossil pollen grains are likely to have been subjected to a greater degree of oxidation and degeneration of their cellulose structures, than their modern counterparts. Chemical techniques are available to remove the extra-exine structures and cell contents from the range of modern samples. Ultimately, these preparation techniques are designed to enhance the diagnostic (sporopollenin) structures of the pollen grain and to present them in a format which is clearly visible under assorted microscope instrumentation.

The preparation of modern pollen follows a routine chemical procedure (refer to Appendix A), with the following major steps: i) teasing open of the flower and the release of pollen from the anthers into an alcohol medium, ii) washing the pollen concentrate in a (0.1 M) solution of sodium hydroxide (NaOH), iii) the application of acetolysis mixture to aid in the digestion of extraneous organic matter (eg, extra-exinous waxes and cellulose), iv) the addition of a visually enhancing safranine stain and, finally, v) mounting the pollen sample on a suitable microscope slide.

The basic chemical procedure requires careful application and frequent modification, especially with respect to delicate palynomorphs. Just as fossil pollen have been shown to undergo differential preservation, so too, contemporary pollen tend to exhibit

differential resistance to the harsh chemical procedures. *Juncus* pollen and the pollen from aquatic plants such as *Zostera* (eelgrass) and *Myriophyllum*, for example, are unable to withstand prolonged chemical oxidation. Trial and error has shown that these delicate pollen types, especially *Juncus* pollen, should not be subjected to prolonged acetolysis; instead a brief wash in NaOH, a neutralising agent and a gentle stain is all that is required to enhance their characteristic structural morphology (personal observation).

Owing to the permanent nature of reference collections, the mounting technique is considered to be the most critical step in the preparation recipe. Numerous different mounting techniques have evolved (eg, Erdtman, 1943, 1969), but the most desirable procedures are those which remain air-tight and limit the chance of oxidation and desiccation. A modified version of Erdtman's (1943) method involves the incorporation of the pollen sample into glycerine jelly which is gently melted (< 45°C) onto the centre of the microscope slide using a calibrated hotplate. Paraffin wax is then melted around the glycerine (the two media are not miscible and exhibit differential melting points) which helps to seal and bond the coverslip over the glycerine-based pollen sample. This technique requires care and patience, especially when applying heat to the microscope slide. Overzealous heating causes tiny bubbles to form in the glycerine which may obscure the detail of the pollen grains by introducing an opaque cloud under the coverslip. An alternative method of mounting permanent pollen samples is detailed by Sugden (1989) who used DPX mountant in preference to wax and glycerine. While the use of DPX avoids the complications associated with heating , it does introduce a higher refractive index than glycerine (> 1.5 as opposed to 1.4) and may contribute to a loss of clarity when attempting to capture photomicrographs. To some extent this complication can be compensated for through the application of a lower density immersion oil and special objective (J Sugden, personal communication), although this does add to the complexity of the technique. Despite the nuances associated with the glycerine jelly and paraffin wax technique, the cost and convenience has made this the preferred technique for mounting the West Coast Pollen (for the comprehensive procedure refer to Appendix B).

7.3 Laboratory techniques for fossil pollen analysis

The basic aim of all fossil pollen preparation techniques is to concentrate the pollen grains and spores that may be present in a chosen sample and to present them in a clear and visible format for identification and counting. This is achieved by progressively removing all extraneous material such as silica and plant debris and any other matrix

that may serve to dilute the concentration or obscure the visibility of the pollen grains. Before physical and chemical concentration of the palynomorphs can proceed, pollen-bearing samples need to be extracted from various positions in the sedimentary sequence. Based on the nature of the investigation, and the specific research questions under consideration, a suitable subsampling interval, and the size of each subsample, needs to be accurately determined.

7.3.1 Physical procedures for subsampling

Polleniferous sediments from the Sandveld were obtained by a variety of different techniques during fieldwork, thereby necessitating different subsampling routines in the laboratory. For example, the samples derived from open sections at Muisbosskerm and Spring Cave were selected from positions located adjacent to significant stratigraphic boundaries. This pre-determined interval was established in the field and the samples required only to be subsampled, proportionally, in the laboratory. The bulk samples from Elands Bay Cave were similarly selected from pre-determined stratigraphic sections and were, therefore, also spatially fixed. The second subsampling routine involved the continuous vibracores derived from Grootdrift and Klaarfontein, which needed to be subsampled along their vertical profile (ie spatially and proportionally).

Following a detailed description of the stratigraphy of each core (refer to Chapter 8 for section drawings and core logs), it was decided that a preliminary assessment of the organic matter content should precede the selection of subsamples for fossil pollen analysis and radiocarbon dating. Organic matter content provides a useful reflection of the balance between production of litter and decay, and is a function of temperature, rainfall, hydrology, nutrient status and the general nature of land use. It was anticipated that a quick assessment, such as loss-on-ignition (LOI) analysis (Dean, 1974), would provide an approximate index of organic matter content so that suitable samples could be selected for radiocarbon dating and fossil pollen analysis. The loss-on-ignition method is less specific than the Walkley-Black titration method (Smith and Atkinson, 1975), but is comparatively simple and less time consuming to perform (Osborne *et al.*, 1993). A 5 ml plastic syringe was modified in such a way that the proximal end (to which the needle attaches) was carefully cut away and opened to expose the full circumference of the syringe barrel. The barrel-rim was beveled to a sharp edge which allowed for the syringe to be inserted into the sediment from which a fixed volume could then be extracted using the gradations on the barrel to accurately gauge the desired amount. Precisely 3 ml (or 3 cm^3) of sediment was extracted, using the syringe method, at 5 cm intervals

along the length of each core, as well as from among the contents of the vials sampled from the open sections. The moist sediment samples were then extruded into dry, heat-resisting porcelain crucibles which were labeled and weighed. This procedure served to establish the relationship between a fixed volume of sample (in this case 3 ml) and its mass (measured in grams). Soil moisture was then eliminated from the samples by maintaining them at 95° C in a drying oven over a period of 12 hours. The dry weights of each sample were then recorded, following which the samples were returned to a furnace for eight hours at 550° C to eliminate the organic matter via combustion. The difference in mass between the dry samples (95° C) and the burnt samples (550° C) provides an index of the total organic content as a proportion of the original dry mass. With the exception of certain archaeological samples which exhibited a high content of shell and bone, the vast majority of Sandveld samples revealed organic matter contents ranging between 0.1 and 14 % by dry mass. The mean organic content of all samples derived from the vibracores from Grootdrift and Klaarfontein was less than 2 % by mass, thereby introducing one of the major disparities between the palynology of arid lands and that of temperate environments, where peat deposits typically yield organic carbon contents in excess of 80 %. Not only did the low organic matter values from Verlorenvlei suggest that pollen densities were likely to be low, but they also indicated that pollen concentration methods would have to contend with large proportions of clastic sediment.

Weinstein-Evron (1987) has investigated various methods of determining the minimum sampling interval required for reliable reconstructions based on fossil pollen from deep sequence cores. While there seems to be no simple solution to this enduring problem, it is recommended that samples are first analysed from a wide interval - usually an arbitrary distance which varies according to the length and age of the core - and that subsequent analyses, if necessary, should proceed at a finer resolution (Weinstein-Evron, 1987). Another pertinent way in which to conduct preliminary investigations is to sample either side of important stratigraphic or chronological boundaries (Birks and Birks, 1980). The apparent stratigraphic complexity of the Sandveld cores suggested that the subsampling routine for pollen should proceed at a resolution of 5 cm, but that preliminary analyses should assess every fourth or fifth sample initially. High resolution sampling intervals (≤ 5 cm) often pose a problem in narrow chambered cores since the volume of sediment required for analyses may equal or even exceed the 5 cm sampling interval. Herein lies a distinct advantage of the wide diameter vibracore tubes, since reasonably large subsamples (eg, 40 g) can be extracted from a relatively narrow horizon (± 1 cm), without having to extend the sampling interval or impinge on the sediment immediately adjacent to the tube walls. A sterile scalpel and spatula were used to

extract each subsample from a narrow horizon not exceeding 1 cm. The subsamples were labeled, sealed in plastic vials and refrigerated until chemical preparation was due to commence. From suitable intermediate and basal organogenic layers, large bulk samples, in the order of 150 - 350 g, were selected for radiocarbon dating. Extreme care was exercised during this procedure so as to minimise the potential for contamination with modern carbon. The samples were dispatched to Dr J Vogel at the Division of Earth, Marine and Atmospheric Science and Technology of the Council for Scientific and Industrial Research (CSIR) in Pretoria for analysis. Owing to the substantial cost associated with radiocarbon dates - usually in the order of R750 - R1 500 each (1995 prices), depending on organic content - only two or three dates, at most, could be obtained from each core.

7.3.2 Preparation for absolute frequency counts

Despite the possible chronological limitations and the anticipated paucity of pollen, absolute rather than relative methods of pollen extraction have been used in support of this study (Birks and Birks, 1980; Fægri *et al.*, 1989; Moore *et al.*, 1991). Absolute pollen counts provide a means of estimating the frequency of individual pollen types, irrespective of alterations in the abundance of other pollen taxa, within a known volume or mass of sediment. When radiocarbon dates become available, the rate of sediment accumulation can be combined with a measure of pollen concentration within it, giving a figure for annual pollen accumulation rates, expressed in grains cm^{-2} $year^{-1}$ (Birks and Gordon, 1985) Although it is recognised that two or even three absolute dates may not be sufficient to accurately determine sedimentation rates in cores of 5 - 6 m (and assumed mid-Holocene age), it is anticipated that additional dates may be established for these cores in the future. As such, information regarding the absolute fluctuations in pollen abundance over time, may prove, in subsequent analyses, to be an important additional tool in the elucidation and interpretation of the Sandveld vegetation and environmental history. For those cores and archaeological sections for which sediment accumulation rates are chronologically secure, the absolute method, described below, is expected to be of immediate benefit to this study since it alleviates many of the statistical shortcomings which beset relative counting techniques (Moore *et al.*, 1991).

Although they offer conflicting advice, Peck (1974) and Fægri *et al*, (1989), provide comparative evaluations of the different methodologies most commonly utilised in the determination of absolute pollen concentrations. Owing to the low pollen frequency anticipated for Sandveld sites, the application of exotic marker pollen to calculate

absolute pollen concentrations, was not considered to be an appropriate method (Jemmett and Owen, 1990). Rather, it was decided to adopt a modified variation of the volumetric methods first described by Davis (1966) and the weighing methods of Jørgensen (1967). Using the measurements obtained during the loss-on-ignition procedure described above, an accurate relationship between mass and volume of moist (and dry) sediment was obtained from each subsampling interval along the length of the core. Provided the chronology of the core is well resolved, the pollen counted from a fixed mass or volume of sediment can be used to calculate i) the pollen concentration at each level, expressed in grains cm^{-3} or grains g^{-1} and, ii) the pollen accumulation rate for each site, expressed in grains cm^{-2} $year^{-1}$.

7.3.3 Chemical procedures for pollen concentration

The general scheme for the concentration of fossil pollen follows a stepwise procedure beginning with manual maceration and coarse sieving of the sample, followed by the major chemical steps: i) removal of unsaturated soil colloids with a basic solution of (0.1 M) sodium hydroxide (NaOH), ii) removal of calcium carbonates by hot, dilute (0.1 M) hydrochloric acid (HCl), iii) digestion of siliceous material through the application of concentrated (0.4 M - 0.6 M) hydrofluoric acid (HF) or, alternatively, the separation of silica using heavy liquid techniques such as zinc chloride ($ZnCl_2$) and, iv) removal of cellulose through the application of acetolysis - a 9:1 combination of acetic anhydride ($[Ch_3CO]_2O$)and concentrated (0.4 M) sulphuric acid (H_2SO_4). Most textbooks provide detailed chemical flowcharts which cater for a wide range of different sediment types (eg, Fægri *et al.*, 1989 and Moore *et al.*, 1991). There is, however, no definitive procedure for the preparation of fossil pollen due to the almost infinite variation in the composition of samples. The highly variable sediment characteristics of the Sandveld, combined with the sensitivity of certain palynomorphs to prolonged exposure to harsh chemicals, particularly hydrofluoric acid, has given rise to a revised method of obtaining absolute pollen frequencies from clay and mineral-rich sediment samples (Appendix C).

Several problems were encountered during the preparation procedure and these are outlined briefly below. The most challenging circumstance was the range of variability that occurred among the sedimentary constituents from one sample to the next and between sequences. This resulted in lengthy delays in processing while alternative chemical procedures were sought to alleviate the problem. The most frequent and time consuming complication concerned the presence of clay-muds in lacustrine/riverine deposits. The deposits from Grootdrift and Klaarfontein were, in some instances, comprised entirely of

aggregated clay-muds which resisted conventional deflocculation techniques. Bates *et al.* (1978) recommend the application of a (0.1 M) solution of sodium pyrophosphate ($Na_4P_2O_7$) as an effective deflocculant, since the charged ions greatly reduce the clay's binding potential with no apparent ill-effect on pollen condition. Despite up to ten repeat applications, there were a number of samples for which the sodium pyrophosphate failed to adequately remove all the clay particles. In some instances, washing alternately in dilute hydrochloric acid and then sodium pyroposphate produced more effective results. The tenacity of certain clays meant that some pollen samples were never entirely free of clastic material and this undoubtedly contributed to lower pollen concentrations and probably less reliable identifications during the counting procedure. The presence of aggregated clay in many samples also mitigated against the use of heavy liquid separation for the removal of coarse siliceous material since the clay, pollen and silica remained trapped in flocs at the bottom of centrifuge tubes. This resulted in prolonged and unavoidable treatments (up to two weeks) in concentrated hydrofluoric acid and it is anticipated that many delicate palynomorphs may have been damaged as a consequence.

The second area of concern relates to the processing of archaeological samples. These cave deposits were frequently rich in charcoal and ash, which, when combined with small amounts of clay produced characteristically 'dirty' pollen samples. For all the archaeological sequences, zinc chloride was used to separate the often substantial mineral component, since it alleviated many of the problems associated with prolonged exposure to hydrofluoric acid. Unfortunately, fine ash and vitrified charcoal also separated out with the pollen and, despite the application of acetolysis to remove organic carbon, this resulted in a grey haze and poor visibility on the final slides.

One of the less obvious but no less frustrating problems related to the facilities at the Univeristy of Cape Town's Palaeoecology Laboratory. While the laboratory equipment is adequate for the preparation of pollen samples from peat-rich sites where the use of 1 - 2 g of sample is typically advocated, the equipment is wholly inadequate for the processing of large volume sediment samples. In particular, the centrifuge configuration (Hermle Z320) is unable to accommodate large swing-out type centrifuge tubes (eg, > 50 ml) and since most sediment samples fell within the range of 5 - 50 g (some were 250 g), this created a logistical problem. Almost without exception, suspensions had to be split into two and sometimes multiple subsamples so that they could be centrifuged in 50 ml centrifuge tubes. Given that certain samples were subject to centrifugation as many as 20 times during the chemical procedure, this raises the question as to how many palynomorphs may have been accidentally discarded along with the supernatant (Jemmett and Owen, 1990). In total, some 250 individual fossil pollen samples were prepared in the laboratory during the period 1991 to 1995.

7.4 Microscopy and identification of fossil pollen

Following chemical purification of the pollen samples and the addition of an aqueous safranine solution to stain the exine structures, the fossil pollen residue was stored temporarily in an accurately measured suspension of tert-butanol (TBA) and phenol. The phenol acts to prevent bacteriological action while the dehydrating qualities and high evaporative potential of tert-butanol makes it ideal for use in the mounting procedure.

7.4.1 Microscope slide preparation

Various mounting media are available and some of these include glycerine jelly, glycerol and silicon oil. All three demonstrate certain advantages and disadvantages, depending on the application intended and the nature of the pollen sample (Moore *et al.*, 1991). For example, it has been noted elsewhere (Fægri and Deuse, 1960) that fossil grains subjected to immersion in glycerine show a tendency to swell up, and that if morphometrics are to be used as a key in their identification, this may lead to erroneous conclusions. However, since many Sandveld pollen grains tend to crumple and collapse during the harsh chemical procedures (personal observation), this tendency of glycerine, together with its excellent optical properties, are considered to be an advantage rather than a disadvantage with respect to identification. As a matter of interest, each of the three media mentioned above were used in support of this study, although the frequent 'grittiness' from resistant silica favoured the use of the higher viscosity glycerine jelly rather than silicon oil. Glycerol was the preferred medium for the charcoal rich archaeological samples since its greater fluidity assisted in the manipulation of pollen grains to gain a better view. The stepwise procedure used in mounting the sample on a microscope slide is documented in Appendix C.

A useful discovery regarding the temporary sealing of microscope slides (personal observation) is detailed as follows: once the carefully measured pollen aliquot (usually in the order of 0.02 ml) has been transferred to the glycerol and the tert-butanol has evaporated, a coverslip is carefully placed over the glycerol-pollen suspension. The suspension should be encouraged to spread evenly so as to fill the entire area beneath the coverslip, but not to extrude from the sides. At this point, a micropipette can be used to administer a thin line of hot, melted glycerine jelly around the edges of the coverslip. On cooling, the glycerine jelly sets to form a delicate yet effective seal around the coverslip and helps to suspend many of the smaller grains that tend to accumulate,

awkwardly, at the margins of the coverslip (Godwin, 1977). While the glycerine jelly serves to bond the coverslip securely in place, individual grains, suspended in the mobile reservoir of glycerol, can be turned and manipulated at will during the identification process, simply by pressing delicately on the coverslip with a dissecting needle.

7.4.2 Procedure for absolute frequency counts

Once the microscope slide has been prepared, the pollen analysis proper can begin. The procedure for absolute frequency counts requires that all (or certainly a very accurate, representative and calculated proportion) of the pollen on the microscope slide needs to be identified and counted. All identification and counting was performed by means of a Zeiss light microscope (Standard Lab, model: 16-8055) at magnifications of X400, and in the case of problematic identifications, X640. Occasionally the use of an oil-immersion X1000 magnification objective was necessary, although this did complicate procedures when reverting to one of the lower powered objectives. A graticule mounted in one of the eyepieces provided an accurate gauge of the size of individual pollen grains but seldom proved instrumental in making identifications. Identification and counting was carried out along regular, evenly spaced traverses, until the contents of the entire slide had been counted. At x400 magnification exactly 50 equal sized traverses are required to scan the entire coverslip. This measure proved useful in calculating the total number of pollen grains where only a proportion of a slide had been traversed and counted. Proportional counting was necessary for slides which demonstrated a high pollen frequency or, in the case were multiple slides were counted, to reach a predetermined 'pollen sum' (Fægri *et al.*, 1989). In these cases, care was taken to ensure that selected traverses were performed at wide intervals so as to take into account the differential dispersal of large and small palynomorphs across the microscope slide (Jemmett and Owen, 1990).

7.4.2.1 *Fossil pollen identification*

Taxonomic identifications of the Sandveld pollen were seldom possible beyond the resolution of the family level, but occasionally, reliable identifications were determined at the genus level. The diversity of pollen taxa from the Sandveld proved, in some instances, to be so overwhelming that the simple task of assigning a family identification proved to be a difficult and time consuming exercise. In total, 67 different taxonomic categories, mostly at the family and genus level, were assigned to the pollen under

investigation. In addition, a large number of indeterminable pollen types were recorded. Following convention (Havinga, 1964; Cushing, 1967), these indeterminable pollen types have been assigned to two sub-categories, namely; 'broken/obscured' (for those types which were either damaged or concealed so as to be unrecognisable) and, 'unidentified' (for those types which could not be assigned to a particular taxonomic group). The taxonomic nomenclature for pollen types usually follows international standards (Berglund and Ralska-Jasiewiczowa, 1986), and where possible, the general conventions set out for the Flora Europaea have been applied to the Sandveld taxa.

7.5 Statistical techniques and data presentation

Data obtained by pollen counts are statistical estimates of the 'true' values of the frequency of pollen taxa occurring in the natural environment. The question concerning the statistical reliability of pollen counts, and of confidence intervals for pollen percentage data, are discussed in great detail by Godwin (1977), Birks and Gordon (1985); Fægri *et al.* (1989) and Moore *et al.* (1991). One of the critical differences between the palynology of arid regions, compared with more temperate parts of the world, concerns the level of confidence attributed to the results (Horowitz, 1992). This relates largely to the differences in pollen accumulation rates and pollen concentration, between temperate and arid environments. For example, Davis (1969 - in Birks and Gordon, 1985), reflecting on research conducted in parts of North America, notes that it is not uncommon to find 500 000 pollen grains cm^{-3} of sediment, and so the availability of pollen in these instances is seldom a limiting factor. By comparison, pollen concentrations in the wetland sediments of Verlorenvlei, yield average densities of 10 - 15 000 pollen grains cm^{-3}, while terrigenous sediments from sites such as Elands Bay Cave, reflect anything from 0 - 3 000 grains cm^{-3}. Clearly, low pollen concentrations result in less pollen for counting and, while pollen counts from selected Verlorenvlei sites averaged around 350 grains per slide, there were large samples (> 100 g) from Elands Bay Cave for which fewer than 10 grains were recorded. The low levels of pollen concentration in the Sandveld introduces two basic statistical problems. The first relates simply to the limited availability of pollen in certain sediments and while this problem may be overcome by repeated analysis of larger samples, this is not always feasible. A practical solution to overcome the problem of low pollen concentrations is through the combination of samples from parallel sequences. This route has, for example, been chosen for the analysis of the neighbouring Grootdrift cores, GDV1 and GDV2.

The other proportional problem concerns the large number of different taxonomic groups that have been identified from the Sandveld samples. In general, arid environments tend to support less diverse parent vegetation and therefore, less diverse pollen. Furthermore, poor preservation conditions in arid environments tend to discriminate against many of the less durable pollen types such that final analysis is often based on only a handful of durable pollen taxa. Characteristically, these taxa usually include the families; Poaceae, Asteraceae and Chenopodiaceae - and, from the relative proportions of these three taxa alone, significant palaeoenvironmental information can be inferred (eg, Horowitz, 1992). By comparison, it would seem that the enormous diversity among the Sandveld parent vegetation, together with reasonable conditions for preservation in the wetland localities, has contributed to an unexpectedly rich diversity of fossil pollen taxa.

Ordinarily, where pollen counts are low, it is safe practice to ignore the minor constituents and concentrate the interpretation on those taxa which have sufficient statistical representation. In the case of temperate zone palynology, much of the palaeoenvironmental interpretation can be inferred from a few dominant arboreal pollen types and the minor constituents (usually non-arboreal types) are statistically ignored. In the southwestern Cape, there are very few arboreal taxa and the overwhelming majority of the pollen types are produced by a diversity of grasses, shrubs, succulents and herbs. Were it not for the low levels of pollen concentration in the Sandveld, the enhanced taxonomic diversity among the pollen counts would be of great assistance in the final analysis. However, given the frequent incidence of reduced counts (150 - 300 grains per sample), the result is that many critical taxa are confined to the role of minor constituents (individually representing less than 5 % of the total proportion) and their significance as *bona fide* indicators, becomes statistically uncertain (Birks and Gordon, 1985). The obvious mathematical solution to this conundrum is to count more pollen. But just how much pollen is needed to maintain the relative confidence limits of, for example, a taxon that constitutes only 1 % of the total? Fægri *et al.* (1989) suggest that in this instance, where the 40 % relative 95 % confidence limits are calculated within a binomial system, a total count of 9 900 grains is needed to keep the limits, 0.8 - 1.2 %. Unfortunately, in regions such as the Sandveld, this introduces a practical and logistical constraint to fossil pollen studies that is not likely to be resolved until reliable automated techniques of counting and identification are developed.

7.5.1 Grouping the Sandveld pollen according to ecological provenance

Probably the most elegant solution to the problem of representivity among minor constituents can be found in the grouping of pollen taxa according to common ecological provenance (Horowitz, 1992). Although some of the interpretative clarity may be lost in the process, grouping allows for greater statistical meaning to be attached to limited pollen counts. The conceptual basis for pollen groupings is established according to environments in which the pollen producing plants are growing, or are assumed to have grown in past times. No strict rules or definitions exist, but the basis on which groupings are made depends on a wide variety of environmental and ecological factors and, of course, the nature of the research question. Scott (1982) reports on the detailed ecological grouping of pollen taxa from the Transvaal bushveld, where as many as eight ecological groups were identified. The problem of overlapping is often unavoidable (the families Poaceae and Asteraceae being a universal point in case), but despite this complication, the value of the technique lies in the improved levels of confidence that accompany the palaeoenvironmental interpretation.

A 'dictionary' of ecological significance has been established for the fossil pollen taxa identified from the Sandveld (Appendix D). Each pollen taxon, with the exception of broken and unidentified palynomorphs, has been assigned to one of six major and thirteen subsidiary vegetation categories. The process of assigning fossil pollen taxa to specific vegetation categories was based on a thorough evaluation of the respective phytochorological, ecological and environmental parameters, as demonstrated by modern equivalents of each taxon, in the contemporary Sandveld environment. The degree of botanical expertise normally required to perform such groupings is clearly beyond the scope of the average palaeoecologist and considerable advice on plant sociology was enlisted from the following sources: Mason (1972), le Roux and Schelpe (1981), Gledhill (1981), Grindley *et al.* (1982), Bond and Goldblatt (1984), Sinclair *et al.* (1986) and Coates Polgrave (1993). Valuable insights were gained from the work of Martin (1968), Scholtz (1986) and Sugden (1989), all of whom document attempts at grouping pollen taxa from other regions in the southern and southwestern Cape. In addition to the published data, a critical appreciation of modern vegetation-pollen relations in the contemporary Sandveld was gained by reference to pollen collected from surface deposits among different vegetation communities (refer to Chapter 6). This approach proved to be among the most useful in defining the major pollen groups, since the compound pollen signature derived from each location, could be compared with

the actual vegetation composition at that location. However, while the modern analogue approach has assisted greatly in assigning fossil pollen taxa to common vegetation categories in the past, it has also reinforced the point that unless taxonomic identifications can be resolved beyond the family level, the procedure remains an inherently intuitive, if not subjective, process.

The ecological dictionary (Appendix D) lists each of the fossil pollen taxa identified from the Sandveld and, where identifications have not been possible beyond the family level, examples of the more common Sandveld species have been included under the heading: typical content. Each taxon includes a corresponding ecological code (ECODE), which is used to assign the pollen type to a particular vegetation category on the basis of its general ecological or environmental provenance. The six major vegetation categories identified from the Sandveld pollen taxa, are:

1. **VELD**. A miscellaneous category which includes the wide-ranging cosmopolitan types such as the ubiquitous Asteraceae, Poaceae and Fabaceae as well as the herbs and ruderal types such as *Oxalis*, Polygonaceae and Scrophulariaceae. The latter three taxa are difficult to assign to any particular ecological provenance, but together with the Asteraceae and grasses offer an indication of extra-local environmental conditions in the so-called 'veld'. On the basis of ecological provenance, the category VELD has been further differentiated into: Asteraceae, Poaceae and herbs/ruderals - each of which may be useful as independent environmental indicators in their own right.

2. **KARS**. This category is comprised of Karroid Strandveld taxa, mostly succulents and shrubs with well developed drought-resisting adaptations. Typical content includes; Euphorbiaceae, Crassulaceae, Mesembryanthemaceae, Aizoaceae, Solanaceae and *Zygophyllum*. The category is conveniently separated into two subdivisions namely; karroid shrubs and succulents.

3. **FYNB**. Dryland Fynbos includes those taxa which have a specific and unambiguous fynbos identity. Typical elements include the four major growth forms; Ericaceae, Proteaceae, Restionaceae and the geophytes: Iridaceae and Hyacinthaceae (formerly Liliaceae). Many other fynbos taxa are present and this has allowed for a distinction to

be drawn between those taxa which have a mesic fynbos identity and those taxa which demonstrate strong xerophytic tendencies.

4. **SCRF**. The Scrub Forest group has proved to be the most difficult to define since it contains elements which overlap between a number of vegetation categories. The general criteria for inclusion in this group is the presence of arboreal pollen from trees and large woody shrubs, elements which are generally indicative of reasonable levels of available moisture. Celastraceae, Ebenaceae, Santalaceae, *Myrica, Podocarpus* and *Olea* are examples from this category. The group is differentiated into two sub-components; coastal elements and drought-deciduous trees of Afromontane origin.

5. **VLEI**. The pollen from wetland (vlei) communities constitutes a large proportion of the overall fossil pollen signature, especially from Verlorenvlei. The more abundant taxa include *Myriophyllum, Nymphoides*, Cyperaceae, *Juncus, Typha* and Chenopodiaceae. Three sub-divisions of the category are recognised, namely: aquatic and semi-aquatic, riparian and halophytic elements. The three sub-divisions are useful in distinguishing between the vegetation from the riverine, lacustrine and estuarine environments.

6. **EXOT**. The exotic pollen from introduced taxa such as *Pinus* spp. have been combined in this category.

Despite the possible drawbacks associated with poor taxonomic resolution, there appears to be considerable merit in attempting to group taxa since, on the one hand, the technique allows for greater significance to be attached to limited pollen counts and, on the other, it allows for interpretations to be made on the basis of all the available data rather than on partial presentations based on the subjective inclusion or omission of selected taxa (eg, Horowitz, 1992).

7.5.2 Presenting the results: the stratigraphic pollen diagram

The pollen analyses have produced large amounts of complex multivariate data which, when presented in a tabular form, are not very useful in eliciting an interpretation. To assist in the interpretation, results are usually displayed in a graphical format referred to as a pollen diagram. Pollen diagrams are designed to provide a coherent visual representation of the complex numerical data in such a way that the reader may grasp the salient features with the minimum of effort. Since most standard texts (eg, Fægri *et*

al., 1989 and Moore *et al.*, 1991) provide detailed accounts of the basic conventions which prescribe the construction of pollen diagrams, no additional review is necessary here. There are, however, a number of acceptable permutations of the standard form and Berglund and Ralska-Jasiewiczowa (1986) provide a succinct yet comprehensive account of the various pollen diagram derivatives which allow ease of comparison of data. Given the nature of the investigation and the specific objectives of the study, the generation of stratigraphic pollen diagrams has been mandatory throughout this study. In brief, stratigraphical and, where available, chronological information has been displayed in a vertical column to the left of the diagram, while the proportions of various pollen types, at each level, are reflected as a series of continuous curves plotted across the horizontal axis. The use of continuous curves is considered to be visually more effective than histograms and, since the sampling intervals are closely resolved for most the sequences, the graphical interpolation of pollen data, which arises between sampling points, is considered to be justifiable.

There are many conventions for arranging the order of taxa across the pollen diagram. Traditionally, these relate to the grouping of dominant arboreal forms to the left of the diagram, which are juxtaposed against the remaining taxa - usually shrubs and herbs - located to the right of the diagram (Birks and Birks, 1980). The pollen data from the Sandveld require a significant departure from this trend since there is very little arboreal pollen in the fossil sequence. Instead, the taxa have been arranged according to their respective ECODES and this order follows the sequence listed in the previous section. This format is conducive to separating the regional and extralocal (terrestrial) pollen from the localised hydrophil (vlei) elements, which are grouped to the right of the diagram, under the heading: aquatic and riparian elements. In the wetland sites of Grootdrift and Klaarfontein, these local vlei elements have contributed to a substantial component of the total pollen, thereby swamping the significance of the regional and extralocal pollen arriving at the site. In an effort to alleviate this problem of representivity, the pollen diagrams from these two vlei sites have been assembled in such a way that the terrestrial taxa have been graphed as a function of the total pollen sum, less the contribution made by the local vlei elements (refer to Horowitz (1992), for details on selective and partial presentations).

All the pollen diagrams presented in support of this thesis were generated with the assistance of the programs Tilia and Tilia•Graph (Version 1.0, Copyright Eric C Grimm, 1991, 1992.). The pre-release alpha version, Tilia 2.0, was used to compile the final pollen diagrams. The Tilia program is especially useful for assigning group codes (ECODES) to the variables (pollen types), while Tilia•Graph provides a wide range of features with which to enhance the graphical representation.

7.5.3 Statistical analysis of the pollen data

The quantitative basis of Quaternary pollen analysis automatically lends itself to numerical and computational methods. In recent years, there has been a growing awareness of the possibility that statistical methods can contribute significantly to the analysis and interpretation of Quaternary pollen data - as witnessed by the increasing number of publications on specialised statistical topics (eg, Gordon, 1982; ter Braak, 1986; Line and Birks, 1990; Janssen and Birks, 1994). Despite recent advances, the original work of Birks and Gordon (1985), *'Numerical methods in pollen analysis'*, remains the single most comprehensive account to date. While there is general consensus that statistical techniques can contribute to palynological investigations, there is also some scepticism about the significance of that contribution (Fægri *et al.*, 1989). Birks and Gordon (1985) also caution against the unnecessary use of, and excessive claims for, statistical techniques, since inappropriate application may lead to false results and misleading conclusions. In respect of this study, the simple nature of the research design and the inherent problems of low pollen concentrations, poor taxonomic resolution, and incongruous sequences have cautioned against a preoccupation with complex multivariate statistical techniques. There are however two basic statistical measures which have proved to be useful in the final interpretation. The first relates to the statistical zonation of the pollen stratigraphic data into coherent pollen assemblages, and the second involves the statistical comparison of modern pollen assemblages with the fossil pollen spectra in order to establish contemporary vegetation analogues for the fossil data.

7.5.3.1 *Statistical zonation of the pollen diagram*

Following construction of the pollen diagram, it is usual practice to separate the graphs into a series of 'pollen zones' to aid in the description, discussion and interpretation of the sequence of vegetation changes which may have occurred through time. A pollen zone is a biostratigraphic unit defined purely by its pollen content and since this is a reflection of the former vegetation assemblage, the term 'pollen assemblage zone' is perhaps more appropriate. Subdivision of the pollen diagram into zones is intended to simplify the information and to construct units which are internally homogeneous with respect to the inferred vegetation composition. It follows that zone boundaries will be placed at the points where change in the pollen spectra are most marked. The delineation of zones and the location of zone boundaries has traditionally

been a subjective process involving visual scrutiny and common sense. Moore and Webb (1978) provide a series of guidelines to assist the researcher in establishing coherent pollen assemblage zones. Over the years, there has been considerable interest in the development and application of numerical methods for the subdivision of pollen stratigrahical sequences (eg, Gordon and Birks, 1972; Birks and Gordon, 1985). The advantage of numerical methods is that pollen zones are specified solely on the basis of mathematical criteria and are not subject to the bias of the individual researcher. Numerical methods which impose a stratigraphic constraint, such as cluster analysis, are useful in delimiting local pollen assemblage zones for independent pollen sequences. Such methods have been employed for the zonation of local pollen assemblage zones from the Sandveld sequences. The application of non-metric multidimensional scaling or principal components analysis is useful for comparing pollen stratigraphical sequences and establishing regional pollen assemblage zones. These techniques have been applied elsewhere in the southwestern Cape by Sugden (1989), but owing to the general lack of contemporaneity between the different Sandveld pollen sequences, attempts to derive regional assemblage zones are of little consequence and, as such, scaling procedures were not applied to the data in this study.

Local pollen zones, carefully defined by mathematical treatment of the available pollen data, are one of the most effective and convenient methods of presenting, succinctly, the mass of information contained in pollen diagrams. CONISS, a program for stratigraphically constrained cluster analysis by the method of incremental sum of squares (Grimm, 1987), has been used to zone each of the Sandveld pollen diagrams. The CONISS procedure was run in conjunction with the Tilia and Tilia•Graph programs and the outputs have been plotted as dendrograms against the pollen diagram. The hierarchical nature of the clusters, determined by CONISS, is such that the technique is able to resolve pollen assemblage zones to levels which are beyond limits of useful interpretation. Therefore, only the first three levels of the dendrogram have been used to determine the placement of the final assemblage zones.

7.5.3.2 *Comparing the modern and fossil pollen spectra*

Statistical comparisons have been attempted between the modern (surface) pollen assemblages and the fossil pollen spectra from the Sandveld. The modern pollen assemblages are useful in establishing patterns of relationship between a range of modern (visually perceptible) vegetation associations and their resultant pollen signatures. Once these relationships have been established, comparisons can be made

between the fossil spectra and the modern pollen assemblages (from known vegetation) on the basis of overall similarities in pollen composition. This is the principal step in the so-called analogue approach to the reconstruction of past plant communities or vegetation types (Birks and Birks, 1980; Birks and Gordon, 1985). Any similarities in the pollen composition and proportions of fossil and modern pollen assemblages can be used as evidence that the corresponding spectra were produced by similar vegetation types - in other words, a modern vegetational analogue can be inferred for the fossil pollen assemblage (Prentice, 1988). In the absence of a satisfactory match between modern and fossil spectra, it can be concluded that the past vegetation has no contemporary modern analogue in the geographical vicinity of the modern sites - though it does not preclude the occurrence of such analogues elsewhere. In this regard, modern pollen data should be extensive and reflect a wide range of contemporary vegetation associations in the context of the study area.

There are a number of methods by which modern pollen and fossil pollen spectra can be compared. Simple visual comparisons of the data, either as tabulated percentages or as pollen diagrams, have been used successfully in studies where only a few pollen types have been the focus of consideration (Davis, 1969). With larger and more complex multivariate data sets, it becomes necessary to employ numerical methods to enable variations in all pollen types to be considered simultaneously and to prevent subjective bias in the comparisons. In recent years, combined numerical classifications of modern and fossil spectra have resulted in the popularisation of geometrical representations in which the spectra are assigned their own separate region in multidimensional space, with residual distances between points reflecting the relatedness of the individual spectra. Principal components analysis (PCA), correspondence analysis (CA) and canonical variates analysis (eg, CONOCO) are some examples of statistical methods that are commonly used to display the affinities of modern and fossil pollen samples (eg, Prentice 1985; ter Braak, 1986). Despite their widespread application, these multivariate techniques suffer from the problem that, in attempting to reduce multidimensional data to two or three dimensional plots for the purposes of computing degrees of similarity between data points, an unpredictable amount of information is lost and there is considerable potential for distortion (Overpeck *et al.*, 1985). For example, multidimensional data points which are plotted in two or three dimensions only may appear to be quite 'close' to each other as a result of their geographical position on a graph. In reality, the nearest neighbours in the plots are not necessarily the nearest neighbours in the original multidimensional space.

In the southern African context, Meadows and Sugden (1991b) have used multiple discriminant analysis in an attempt to establish the degree of analogy between modern pollen assemblages and fossil groups from the Cederberg mountains. While the application of discriminant analysis avoids some of the limitations of multivariate analyses, it does include some degree of subjectivity as the samples have to be classified into *a priori* groups or vegetation types before analysis can proceed. Furthermore, the applicability of the technique is critically dependent on a number of statistical assumptions (MacDonald and Ritchie, 1986), which are not adequately addressed in this study.

In support of the fundamental aims and objectives as set out in Chapter 1, and in consideration of the complex and problematic nature of the Sandveld pollen data (high taxonomic diversity, low pollen representation), a simple statistical approach (which does not rely on multidimensionality) has been advocated for use in comparing the modern and fossil pollen spectra (L Underhill, personal communication). Such a method is one which utilises the entire pollen data set to compute the Euclidean distance between each of the modern pollen assemblages and each of the fossil pollen spectra - without the prejudice of selective taxonomic omissions and weighting factors that have come to be associated with techniques such as correspondence analysis (Birks and Gordon, 1985). For details of the statistical algorithm refer to Appendix E.

The Euclidean distances are based on converting each sample to its taxonomic composition in proportions (including the minor elements and rare pollen types). Ultimately, each fossil pollen spectrum can be expressed in terms of a measurable factor of their nearest modern analogue or so-called 'Nearest Neighbour Index' (NNI) using a scale from 0 - 1, with small values being closest and large values more distant in their affinity or 'neighbourliness'. This form of comparison is especially useful in that it provides a tangible measure of the similarity or dissimilarity of fossil pollen spectra with respect to analogues of modern vegetation.

7.6 Summary and conclusions

The first step in the sequence of fossil pollen analysis is to guarantee the identification of the fossil palynomorphs. For the Sandveld pollen, this was accomplished through the establishment of a reference collection of pollen of known origin. Herbarium pollen, specifically representative of West Coast taxa, was used to augment the CTCP. Preparation of the fossil pollen material from late Quaternary deposits follows a stepwise

procedure during which all extraneous non-polleniferous material is removed and the pollen grains are concentrated in sufficient quantities to allow for identification and counting. A variety of graphical and statistical techniques is available to augment the presentation and interpretation of pollen data. Pollen diagrams reflect the results in a sequential, graphical format, while numerical comparisons of modern and fossil pollen spectra are able to provide useful diagnostic information. A range of numerical methods is available to assist the palaeoecologist to produce a more informed and more quantitative reconstruction based on multiple sources of data. Yet, despite the allure of complex statistical treatments, the final interpretation will always depend on a thorough knowledge of the ecology and sociology of the taxa concerned and of patterns and processes operating in the environment.

Chapter 8

RESULTS AND DATA INTERPRETATION

8.1 Introduction

In a scientific thesis, it is customary for results to be presented objectively and unambiguously in an independent 'results' chapter. Interpretation of these data, which is invariably a subjective exercise, is normally reserved for discussion in a following section. This is a sensible strategy for investigations which deal with one or two principal data sets, but may lead to a loss of clarity when results are presented from multiple sources of information. In view of the fact that the data presented here are derived from six independent pollen sequences and three additional sedimentary sequences, it is the author's conviction that continuity will be compromised if the respective palaeoenvironmental reconstructions are dissociated from the results. Thus, the data from each of the Sandveld sites are subject to detailed palaeoecological interpretation in this chapter. No attempt, however, is made to synthesise the findings or draw substantive conclusions. This task is reserved for discussion in Chapter 9, in which the data are assessed collectively in terms of the broad research question and the original aims and objectives of the study as delineated in Chapter 1.

Presentation of the fossil pollen data has two aspects, the factual and the selective. Both aspects are presented here. Factual presentation of the results takes the form of raw data where no statistical treatment or any form of manipulation - graphic, numerical, selective or otherwise - has been performed. For each Sandveld site described in this Chapter, the raw pollen counts are supplied in matrix format (Appendix F). Factual data include: i) the absolute pollen counts, ii) the sample interval expressed in cm depth and, iii) the concentration of pollen grains expressed in both grains g^{-1} and grains cm^{-3}. Where applicable, the sediment accumulation rate (mm $year^{-1}$) and the pollen accumulation rate (grains cm^{-2} $year^{-1}$) have also been calculated (for details on the method of calculation refer to Appendix G). Although there is little interpretative benefit attached to this form of factual presentation, it is unquestionably the most objective format and has the added advantage of allowing for the data to be subjected to any number of independent treatments, statistical or otherwise, by future researchers.

To assist in the actual palaeoenvironmental interpretation, fossil pollen data are presented selectively, in graphic format. A suite of continuous curve pollen diagrams has

been constructed for each of the fossil pollen sites. This Includes: i) a comprehensive pollen diagram which illustrates the total pollen taxa in their most resolved format, ii) a summary pollen diagram in which the pollen data are grouped according to established ecological provenances (their so-called ECODES) and, iii) a cumulative pollen diagram which provides a quick and effective visual résumé of the changing proportions of the grouped pollen taxa through time. All the Sandveld pollen diagrams, with the exception of the recent sites and Elands Bay Cave, are based on absolute pollen counts of all identifiable pollen at each sampled level. In the case of Elands Bay Cave, the pollen data are presented in a pollen-presence diagram, since the limited pollen counts do not permit presentation in the resolved format. Where applicable, each of the pollen diagrams has been divided into different pollen assemblage zones with the assistance of stratigraphically constrained cluster analysis, performed by the method of incremental sum of squares (Grimm, 1987). The modern pollen data, collected from different surface sites in the Sandveld, are stratigraphically unconstrained and therefore take the form of a resolved histogram rather than continuous curve format.

Comprehensive stratigraphic descriptions of all the cores and excavations are presented in detailed core logs and section drawings. Stratigraphic depths have been recorded in metres, while descriptions of pollen sequences, which generally require finer resolution measurements, are recorded in centimetres. Where available, radiocarbon (^{14}C) chronology and stable carbon isotope values ($\delta^{13}C_{PDB}$) have been recorded along with notation from Munsell Soil Color Charts (1975). Graphic illustrations of pollen concentration (grains cm^{-3}), pollen accumulation rate (grains cm^{-2} $year^{-1}$) and organic matter content (mol mg^{-1}) are presented for certain sites.

8.2 Modern pollen sedimentation in the Sandveld

The reliability of fossil pollen as useful quantitative information on ancient vegetation is critically dependent on the relationship between modern vegetation and the ensuing pollen signature. Indeed, without good knowledge of modern pollen deposition in sedimentological environments which are analogous to those of the fossil sites, interpretation of fossil pollen data is often difficult. This section aims to present the palynological results obtained from 19 surface samples collected from a variety of floristic environments in the Sandveld (refer to Table 6.4 for specific phytogeographic details). The surface sites were chosen from a diverse range of sediments and these include saltmarsh sediments, spring sediments, wetland sediments, dryland sediments, cave deposits and hyracium middens.

8.2.1 The modern (surface) pollen diagrams

For each surface site, the choice of sample size and processing procedure was dependent on the nature of the deposit, although, for the most part, larger samples up to 200 g each, were used for processing dryland surface samples. Counting was performed until 600 grains, including unknown taxa, had been counted. Relative percentages have been calculated against the total pollen count, including unknown grains, but less the contribution of spores. The hyracium sample has been excluded from the quantitative analysis on the basis that it is dominated by asteraceous pollen and does not offer a reliable index of the modern vegetation surrounding the contemporary midden site. The 18 remaining pollen assemblages are plotted together on the histograms (Figures 8.1 and 8.2). In both pollen diagrams, the spectra are plotted in sequence, from top to bottom, according to their respective position along an environmental/altitudinal transect that stretches from the Piketberg highlands in the east to the Verlorenvlei mouth and Wadrifsoutpan on the West Coast (refer to Figure 3.3 for a visual appreciation of this transect). Figure 8.1 presents the 18 modern pollen assemblages in their most resolved taxonomic format with identifications made at the family and generic levels. Figure 8.2 presents the same data in a more succinct format with the pollen of each assemblage grouped according to common ecological provenances (ECODES) - as delineated in Chapter 7. This latter graphic format is easier to translate and is visually more comprehensible, thus allowing for simple visual comparisons to be drawn with similarly grouped spectra from the fossil pollen sites.

8.2.1.1 *Modern vegetation-pollen relations*

It is significant to note that from the 18 samples analysed, 50 indigenous taxa have been identified, including 8 Afromontane Scrub Forest taxa, and 36 West Coast Strandveld and Dryland Fynbos taxa. The total number of taxa identified from each spectrum varies between 11 and 33. The main pollen transporting agent is considered to be wind, while water is expected to play a secondary role in the transport of pollen in the wetland environments. Asteraceae, Poaceae and Restionaceae are the most abundant terrestrial pollen taxa (up to 20 % each), while the pollen from a combination of emergent reed types and the Chenopodiaceae are seen to dominate the wetland environments - with the exact composition depending on the salinity factor at the particular location. The variations which occur in the pollen from wetland sites is ascribed largely to the local conditions which favour the growth of certain plants or plant

Figure 8.1 Modern (surface) pollen spectra from 18 Sandveld sites

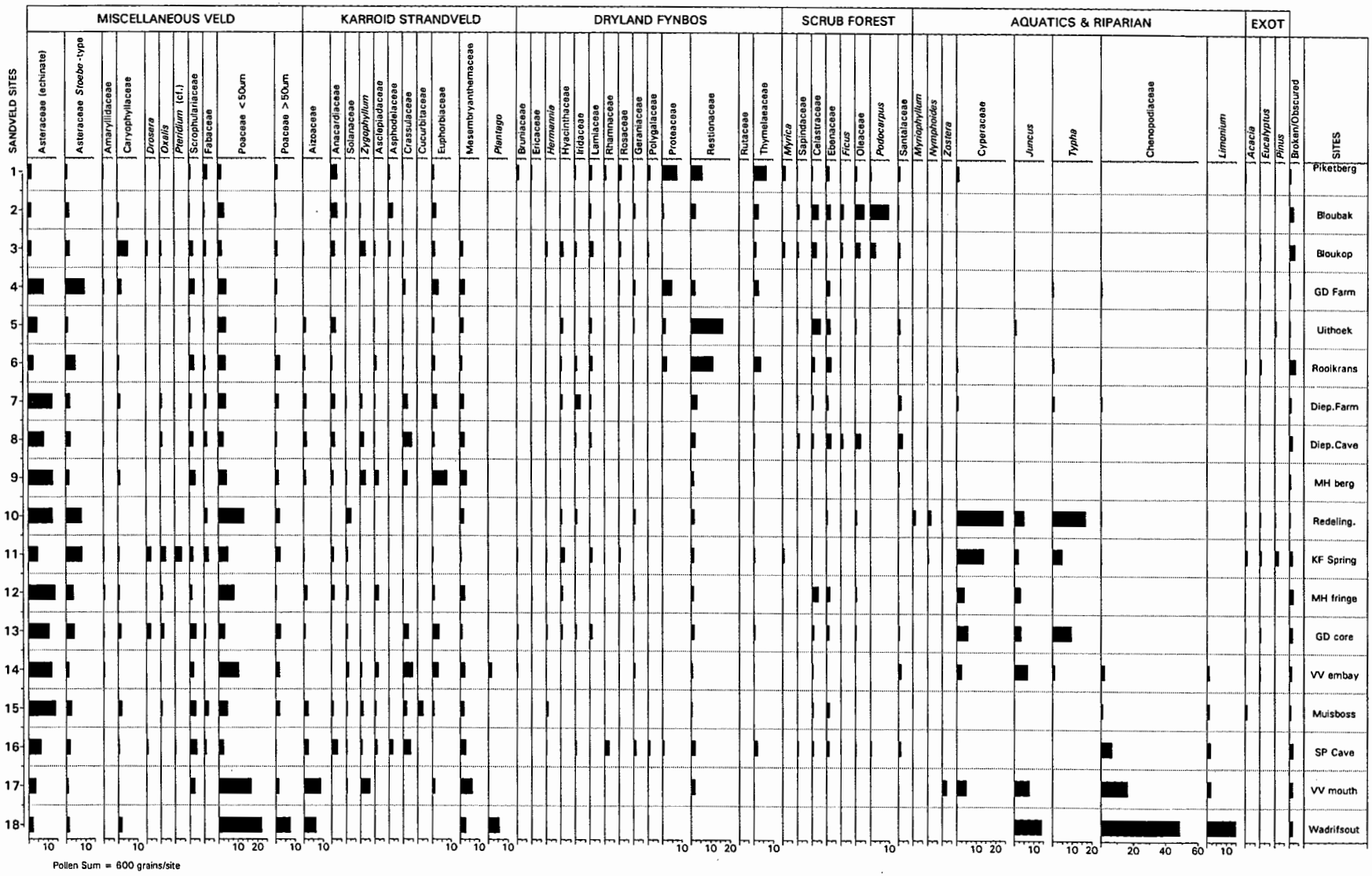
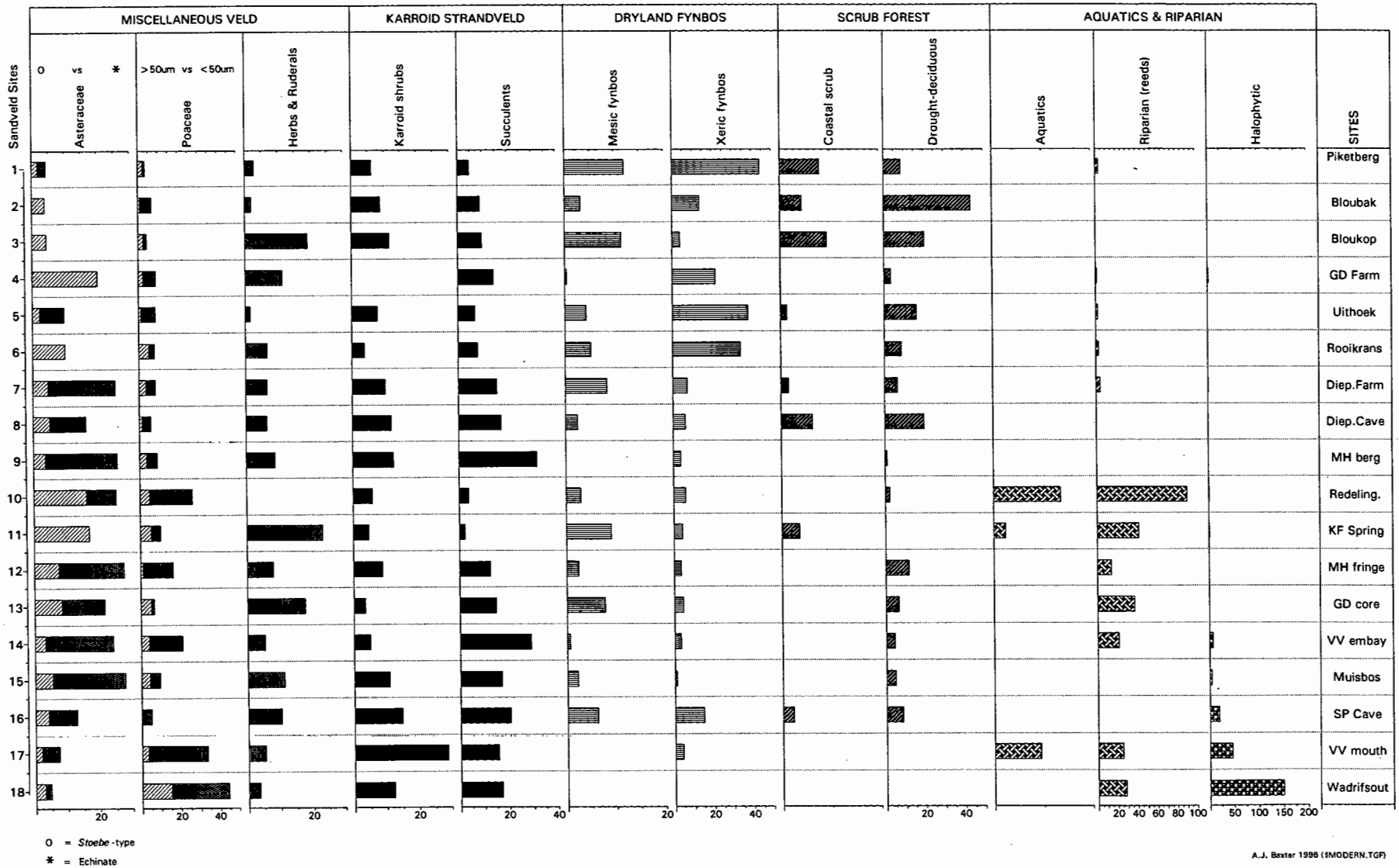


Figure 8.2 Modern (surface) summary (ECODE) pollen diagram



associations. These conditions are usually related to substrate and limnology. In general, *Typha* and Cyperaceae show higher proportions towards the proximal end of the Verlorenvlei system, while *Juncus, Limonium* and Chenopodiaceae are more common in the distal, hypersaline reaches. Fynbos and scrub forest pollen are generally rare in the surface spectra although samples such as Piketberg (spectrum No.1) and Bloubak se Koppe (spectrum No.2), which were selected from dense stands of Dry Mountain Fynbos and Afromontane Scrub Forest respectively, exhibit distinctive pollen signatures.

In general, the modern pollen data set reveals a close relationship between the pollen spectra and the vegetation communities producing them. The spectra are comprised of a mixture of autochthonous and allochthonous types which represent all the main vegetation elements occurring in the northern Sandveld. In terrestrial sites, low arboreal representation is offset by a greater abundance of herbaceous and succulent taxa, while wetland sites reflect the predominance of localised halophytic and hydrophytic elements. These vegetation-pollen relationships are consistent with the picture of modern pollen sedimentation derived from other arid regions of Africa (Vincens, 1987) and highlight the potential of local pollen to 'swamp' or dilute the pollen signal from extralocal and regional terrestrial elements. There are, nevertheless, significant proportions of pollen of grasses and asteraceous shrubs in these wetland spectra to suggest that they may provide a reasonable indication of vegetation changes in the wider catchment. Terrestrial surface samples are generally free of the bias from local aquatic elements but also indicate that extralocal trees and shrubs are not good pollen producers and/or that many of these plants are entomophilous. In summary, the modern pollen spectra provide a good picture of the regional vegetation, especially when grouped into community types, and despite the predominance of local elements, it is very much a case of 'what you see is what you get'.

8.2.2 Comparing modern and fossil pollen spectra

With adequate levels of correspondence apparent between the modern pollen signature and existing parent vegetation in the Sandveld, comparisons have been drawn between the fossil pollen spectra and the modern pollen spectra on the basis of overall similarities in pollen composition. A statistical algorithm (refer to Appendix E) has been used to compute the Euclidian distance (Nearest Neighbour Index or NNI) between each of the 18 modern assemblages and each fossil spectrum from all of the Sandveld sites. Appendix H contains a comprehensive list of the NNIs, for each level at each site, sorted from nearest to furthest neighbour (ie 'most similar' to 'most dissimilar' modern

analogue). The indices range considerably, with the closest neighbour being 0.08 and the most distant being 0.92, suggesting that a wide spectrum of floristic variability is implicit in the fossil data. Interestingly, the most frequent *closest* analogue is the Strandveld vegetation that occurs on the slopes above the Verlorenvlei Farm embayment while the most frequent *distant* analogues are the saltmarsh vegetation at Wadrifsoutpan and the dense thickets of Mountain Fynbos along Piketberg. Where significant, the NNIs and modern analogue sites have been used to substantiate the vegetation history reconstructions which follow in relevant sections of this chapter.

8.3 The Grootdrift boreholes

To date, multidisciplinary investigations of the Grootdrift borehole sediments have yielded preliminary results on pollen analysis (Meadows and Baxter, 1992), sedimentology and textural analysis (Erlank *et al.*, 1992), stable carbon isotope analysis of carbonate-free whole sediment (Sealy, 1992), and palaeomagnetic reconnaissance (Hyaashida and Yokoyama, 1992). In the absence of radiocarbon dates, many of these results remain inconclusive and are not intended to form part of this study. However, recent sedimentological and chronological evidence, gathered from alternative sites in the Verlorenvlei catchment, has provided the impetus for a re-interpretation of the sedimentology from the Grootdrift boreholes.

8.3.1 Stratigraphy and sedimentology

The Grootdrift boreholes, GDN and GDS, produced intermittent cores measuring 11.70 m and 17.50 m respectively. The PVC core liners, containing the sediments, were returned to the laboratory at UCT and split by the author, in accordance with the cutting technique normally employed to separate aluminum vibracore tubes. Prior to subsampling by members of the research consortium, the stratigraphy of the cores was described and logged (refer to Figure 8.3 (a) for the log of GDN) In general, both cores reveal abrupt variations within their sedimentary constituents - a feature which is largely attributable to the discontinuous nature of the sampling regime. Basal sediments contain pebbles, coarse gravel and sand, a clear indication that the boreholes had terminated in proximity to disagregated bedrock. Towards the surface, both cores reveal banded structures comprising fine ochrous clays interspersed with layers of coarse sand and muddy gravel. The most salient stratigraphic feature, common to both cores, is the presence of greenish-grey (10GY 7/1) muddy sands at a depth of approximately 4.75 m

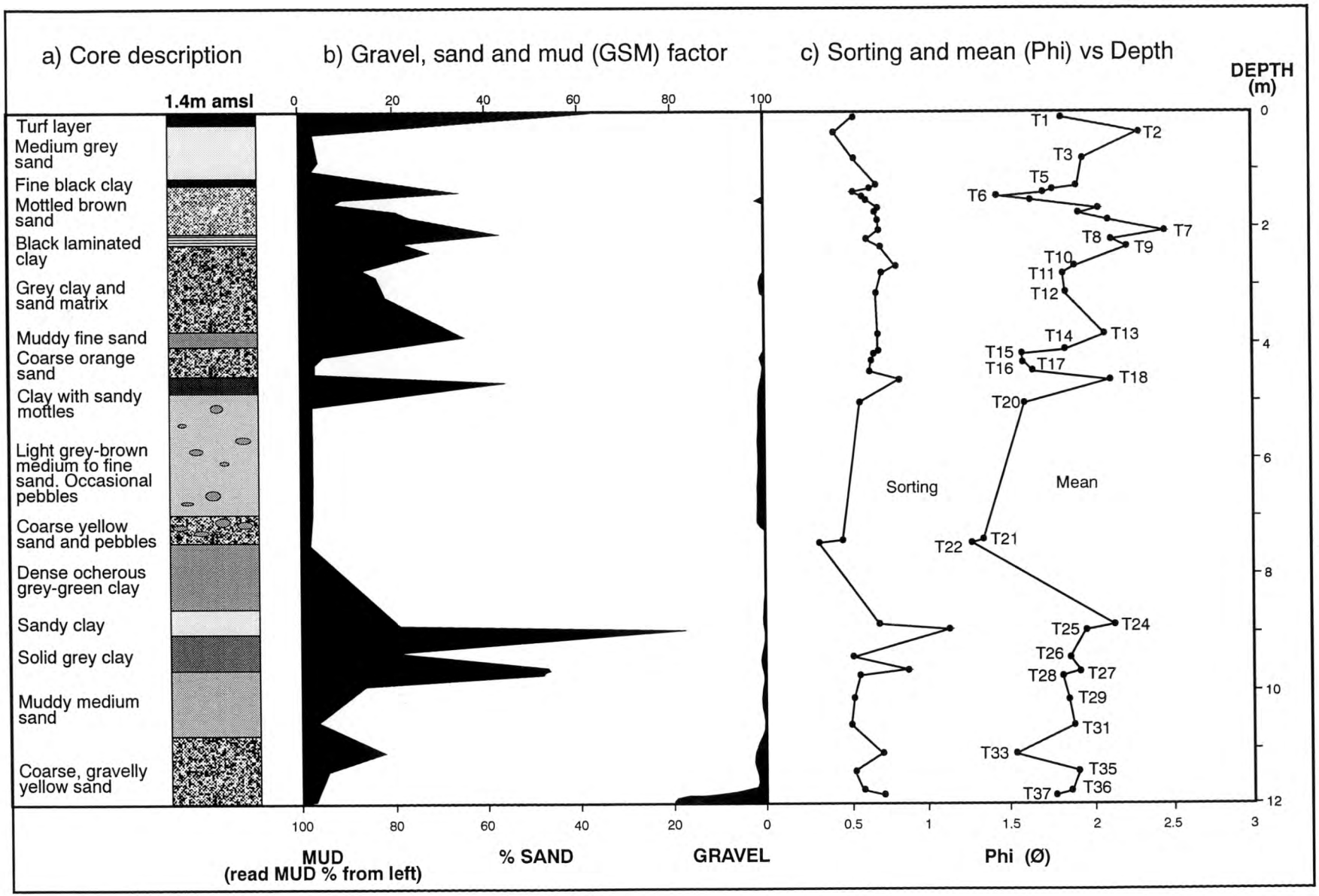


Figure 8.3a-c Core log and textural analysis of GDN. Adapted from Erlank *et al.* (1992).

and 9.00 m in GDN, and 5.00 m and 8.50 m in GDS. Given that the top of GDN is presently at 1.4 m amsl and the top of GDS is at 4.5 m amsl, there appears to be few direct correlations between the stratigraphy of the two cores. In view of the poor recovery and intermittent nature of GDS, no reliability can be attached to the sedimentary record from this site and no further results are presented from this core.

Despite the application of a number of diverse scientific investigations, logical interpretation of the Grootdrift GDN borehole material has, until recently, remained largely elusive. Firstly, the erroneous application of a polymer-based drilling mud and vlei water prevented the accurate age determination of the core material by radiocarbon dating. Secondly, the sedimentological analysis reported by Erlank *et al.* appears to be confused by the lack of chronology and the apparent reworking of former marine deposits by subsequent fluvial and aeolian processes. As a result, definitive statements concerning the nature, timing and depositional context of the Grootdrift sediments have not been forthcoming. Thirdly, the poor capture and intermittent recovery of core material has predetermined a wide sampling interval and limited the volume of sediment for pollen and other microfossil analyses. Finally, in the absence of any supporting microfossil data, interpretation of the stable carbon isotope analysis of the GDN borehole sediments has remained problematic.

To some extent, these initial limitations have been overcome by new chronological, palynological and sedimentological information gained from the vibracores taken at Grootdrift, Klaarfontein and the Verlorenvlei Farm embayment. These new findings have allowed for a re-interpretation of Erlank *et al.*'s sedimentological data from GDN (Figure 8.3 (a-c) illustrates the core log and results of the original textural analysis from GDN). The implications of the new data, particularly with respect to the re-interpretation of the sequence of fluviatile-estuarine sediment dynamics at Grootdrift, and sea-level rise, are explored in conjunction with the results from the Verlorenvlei Cottage core in section 8.9.

8.4 The Grootdrift vibracore transect

Of the seven vibracores derived from the Grootdrift transect, three cores, GDV1, GDV2 and GDV4 have since been utilised for detailed palynological investigation. Figures 8.4, 8.5, 8.6 illustrate the core log information from these respective sites (note that GDV1 and the uppermost 5 m of GDN are effectively the same core). Of the remaining cores from the Grootdrift transect, the surface sediments of GDV3 reveal disturbances which may relate to the foraging habits of cattle observed at this location (personal

observation) and, as such, the value of investigating this core has remained questionable. The cores GDV5, 6 and 7 are believed to contain a broadly similar depositional sequence to those of GDV1, 2 and 4 and have therefore been logged and archived for possible future investigation.

8.4.1 Stratigraphy and chronology

Four radiocarbon dates were derived from distinct organic facies subsampled from GDV1. Darker layers around 4.54 m, 4.00 m, 2.29 m and 1.35 m have yielded dates of 5 550 ± 70 BP (Pta 5807), 5 070 ± 110 BP (Pta 5809), 4 340 ± 60 BP (Pta 5812) and 300 ± 45 BP (Pta 5814), respectively. The stratigraphy, as might be expected for sediments deposited in a dynamic alluvial / fluvial / lacustrine / estuarine / lagoonal environment, is complex. It becomes obvious on examining the distribution of radiocarbon dates that there is a hiatus in the sequence at 1.41 m below the surface. Table 8.1 shows that sediments accumulated in the Verlorenvlei at Grootdrift between 5 000 BP and approximately 3 800 BP at the mean rate of just under 2 mm year^{-1}. This is the range to be expected for a sub-arid estuarine environment, as demonstrated by the work of Petersen *et al.* (1984), Davis (1992), and Cole and Liu (1994), who report on the Holocene accumulation of estuarine sediments from different sites in the western and northwestern United States. Deposits aged between approximately 3 800 BP and 300 BP are not present in the sequence, either because they were subsequently eroded or because sediment accumulation ceased locally. Sediments at GDV1, then, represent some 1 800 years of accumulation after 5 550 BP followed by a hiatus and superseded by the last 300 years of deposit.

DEPTH (IN CM)	INFERRED TIME INTERVAL	ACCUMULATION RATE
141 - 0	300 radiocarbon years	4.7 mm yr^{-1}
229 - 141	4040 radiocarbon years	0.2 mm yr^{-1}
400 - 229	730 radiocarbon years	2.3 mm yr^{-1}
454 - 400	480 radiocarbon years	1.1 mm yr^{-1}
454 - 229	1210 radiocarbon years	1.9 mm yr^{-1} *

Table 8.1 Sediment accumulation rates at Grootdrift (GDV1). *Calculation based on overall mean sediment accumulation rate from 454 - 229 cm.

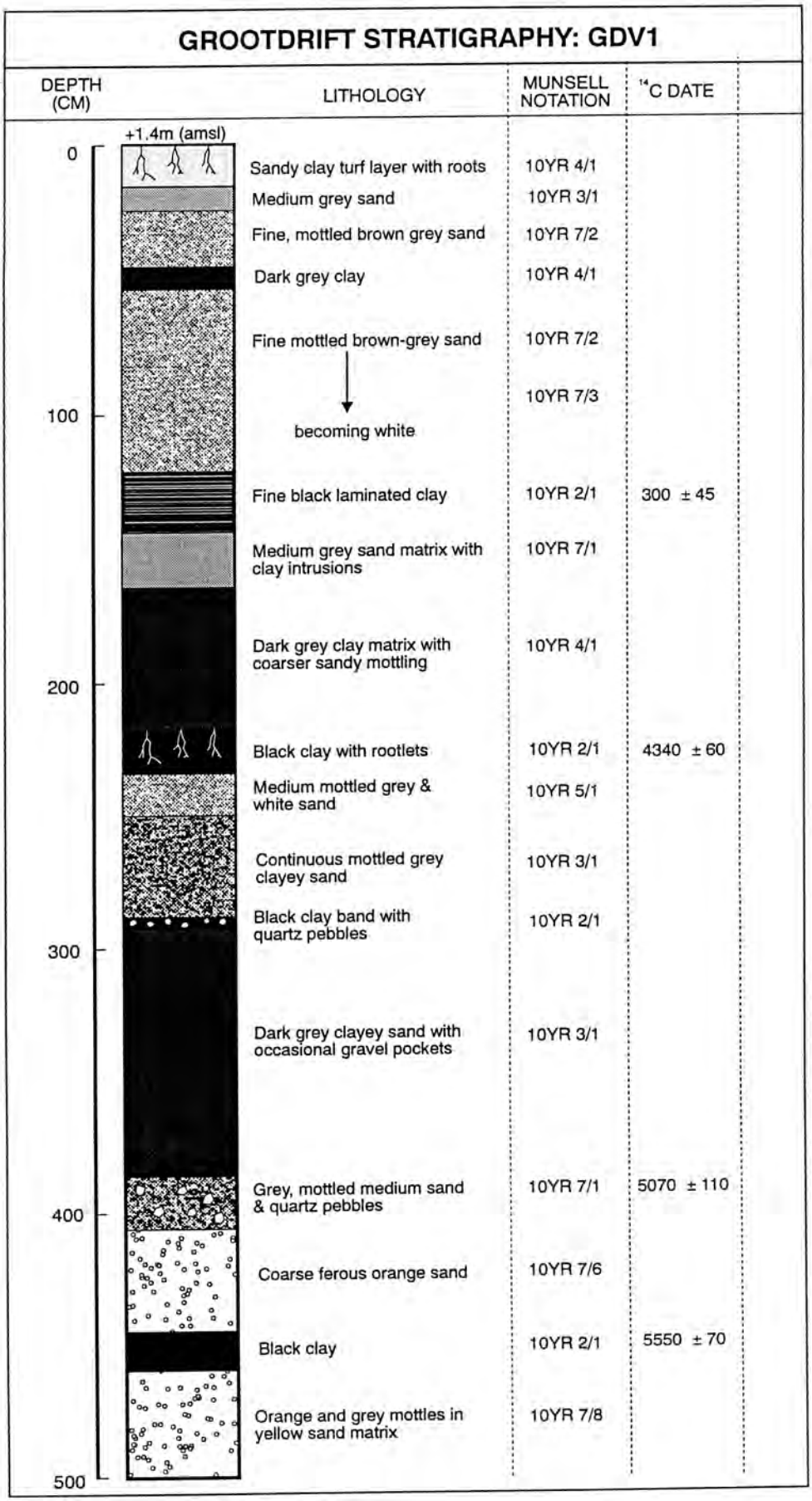


Figure 8.4 Grootdrift stratigraphy : GDV1.

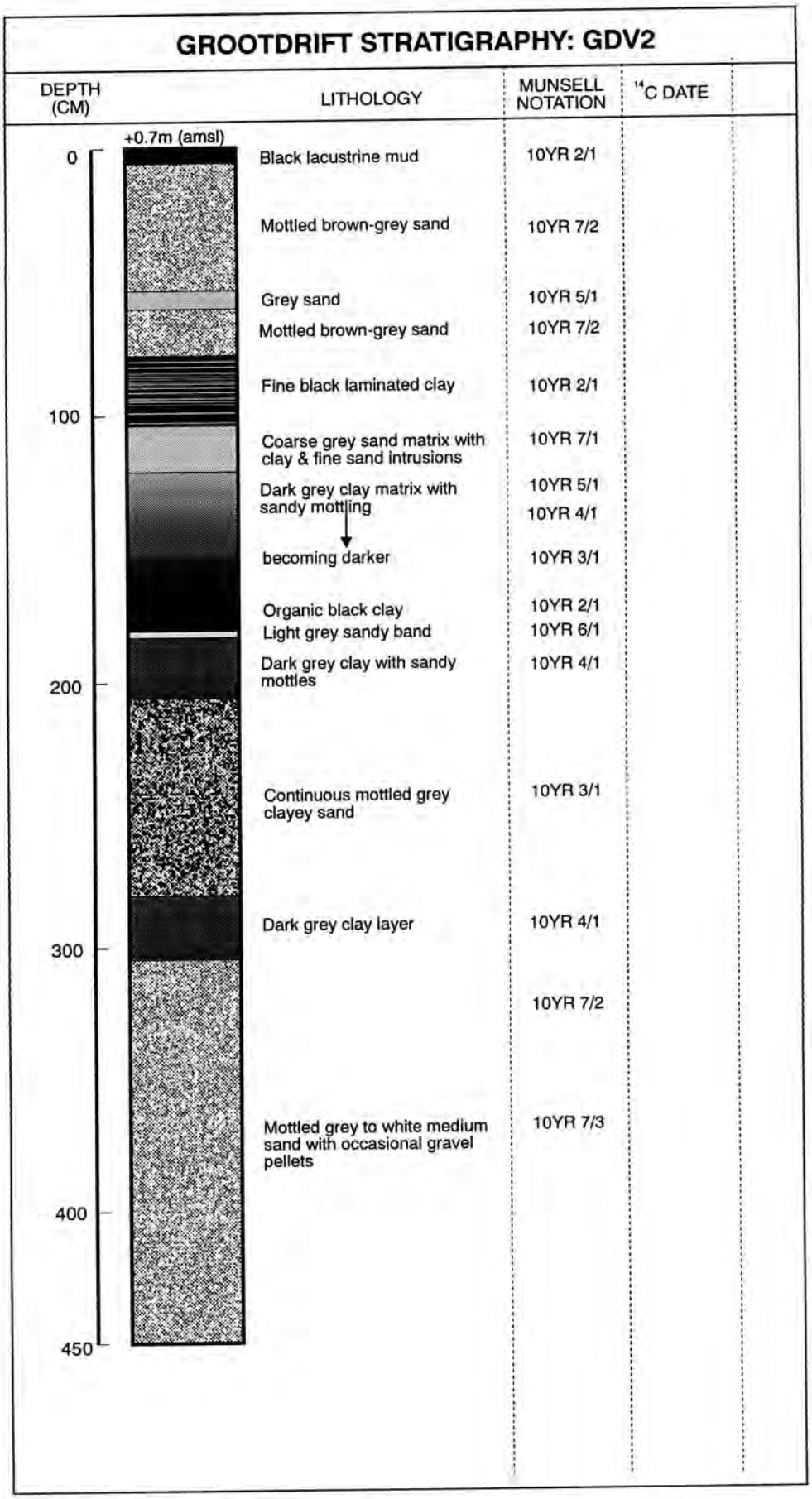


Figure 8.5 Grootdrift stratigraphy : GDV2.

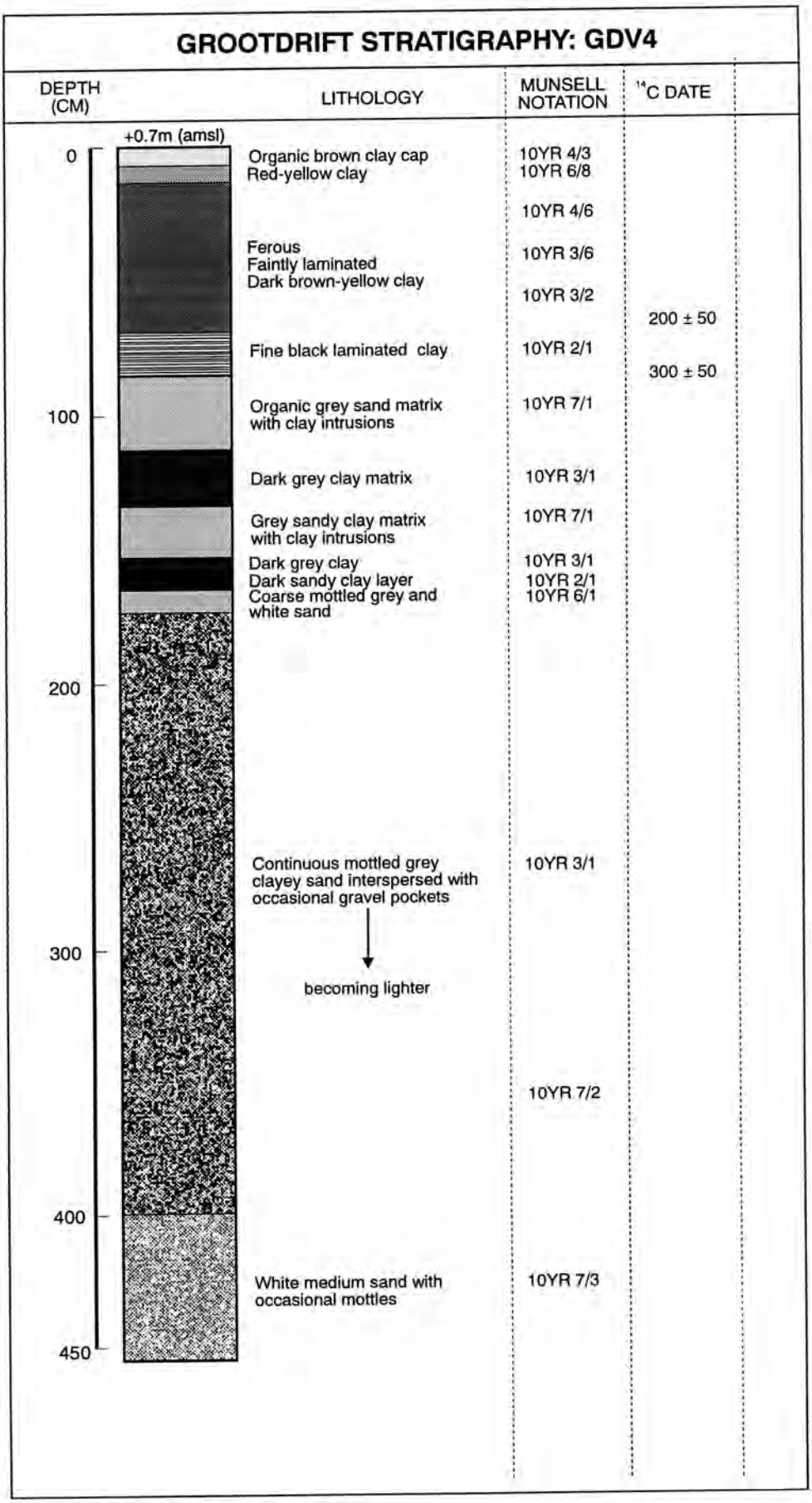


Figure 8.6 Grootdrift stratigraphy : GDV4.

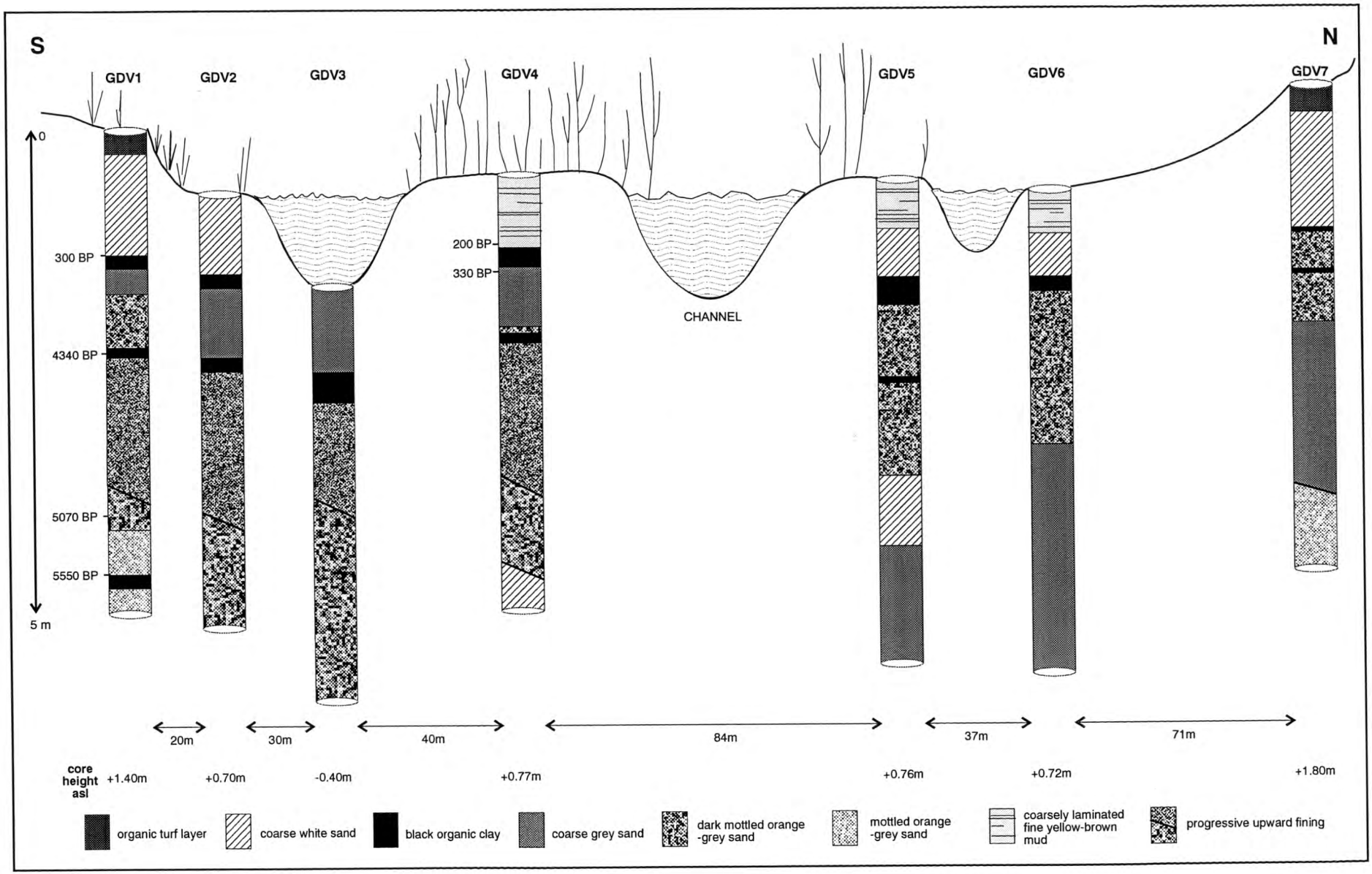


Figure 8.7 Cross-sectional stratigraphy of the Grootdrift vibracore transect.

In considering the cross-sectional stratigraphy across the vibracore transect, a number of interesting observations regarding the depositional facies have been noted (Figure 8.7). For example, the organic horizon recorded at 2.29 m in GDV1 appears to be a coherent spatial feature that extends partially across the Grootdrift transect at a relative elevation of around –1 m ± 20 cm amsl. Although this feature is recorded among cores GDV1 - GDV5, the feature is absent in GDV6 and indistinct in GDV7, prompting the speculation that a palaeochannel, located along the northern margin at Grootdrift, may have selectively removed this sedimentary feature, or prevented its accumulation, some time between 4 300 and 300 BP. The cross-sectional stratigraphy also suggests that the sedimentary hiatus, during this latter period, was a widespread phenomenon at Grootdrift.

The most significant stratigraphic feature of the Grootdrift vibracore transect occurs nearer the surface, at a relative height of 0 m ± 20 cm amsl. First recorded in GDV1 at a depth of 1.28 - 1.42 m, and dated to 300 ± 45 BP (Pta 5814), this distinctive black organic-rich 'marker' (up to 25 cm in thickness) is evident in all but one of the seven transect cores (Figure 8.7). Indistinct muddy sediments towards the top of GDV3 suggest that at this particular location, the feature may have become incorporated with more recent sandy sediments - a possible consequence of bioturbation by foraging cattle in the open water pond that characterises this core location. Despite the confusion in core GDV3, the organic horizon is otherwise consistent both in its composition and depositional location in each of the remaining six transect cores. In an effort to further improve the age resolution of the organic marker, additional radiocarbon dates were sought from this horizon. Samples derived from the GDV4 core date the base of the organic pulse to 330 ± 50 BP (Pta 5910) and the top of the horizon to 200 ± 50 BP (Pta 5908). These recent radiocarbon dates have been calibrated to calendar years according to Talma and Vogel (1993). In the case of GDV4, the dates carry respective calibrations of AD 1640 (with a 1 σ range of AD 1618 - 1654), and AD 1747 (with a 1 σ range of AD 1678 - 1799). Although the absolute chronology of sedimentation after this latter date has yet to be accurately established for Grootdrift, the finely laminated stratigraphy and general consistency of the upper lacustrine clay-like sequence in the GDV4 core, suggests that sediments have accumulated in the central wetland in provenance and without interruption since 200 ± 50 BP to the present day.

A slightly different picture emerges for those cores derived from the modern banks at Grootdrift. By comparison to the cores located within the wetland, the sedimentation rates of GDV1, along the southern margin, and GDV7, along the northern margin, appear to have increased substantially during the last few hundred years. In these peripheral cores, the black organic marker, radiocarbon dated in GDV1 to 300 BP, is overlain by

medium-grained, white to brown, mainly quarzitic sands. In both GDV1 and GDV7, these sterile sands extend up for 1.30 and 1.50 m respectively until they are capped by the modern organic facies at current surface level. Clearly, these sandy stratigraphies, immediately above the organic marker, herald an abrupt departure in the former depositional regime along the vlei margin. Although it is tempting, on the basis of sedimentation rates alone (± 5 mm $year^{-1}$), to suggest that infill sedimentation from the adjacent slopes has more than doubled during the historical period (refer to table 8.1), the limitations imposed by large standard deviations attached to the recent radiocarbon dates, renders this, for the time being, a speculation. Of greater conclusive value, the organic marker at Grootdrift is shown to have been a consistent environmental phenomenon that permeated across the valley floor. In fact, its presence in cores GDV1 through GDV7 suggests that the modern wetland has reduced in width by at least 60 m (25 %), since *circa* AD 1750 - and this despite present water levels being artificially raised and impounded by a causeway construction lower in the Verlorenvlei system (Robertson, 1980).

8.4.2 The Grootdrift (GDV1&2) pollen diagrams

Fossil pollen analysis has been performed on cores GDV1, 2 and 4. Preliminary investigations first centred on GDV1, and for the initial study, a wide subsampling interval of 20 cm was prescribed. Since the organic content of the GDV1 sediments is extremely low (1 - 5 mol mg^{-1}), special attention was given to the removal of clastic material, including clay and coarse-grained quartzic sand. In order to ensure sufficient pollen for counting, large subsamples measuring approximately 20 g each were selected from the length of the core. Pollen counts were performed until each slide had been completely traversed or at least 200 grains had been identified from a known proportion of the slide surface. In practice, many samples were poor in pollen and despite the analysis of multiple slides (up to six), certain samples failed to achieve total counts of more than 40 or 50 grains. As a consequence, a concerted effort was made to improve both the level of pollen concentration and the sample resolution during subsequent analyses. Unfortunately, multiple subsampling of the GDV1 core had left very little undisturbed material for further analysis. This prompted the use of the neigbouring, stratigraphically-aligned GDV2 core, as a surrogate. Beneath the upper organic marker, the stratigraphy of GDV2 is consistent with that of GDV1 and additional pollen samples were derived from a subsampling interval of between 5 and 15 cm. Levels of pollen concentration for both GDV1 and GDV2 are consistently low (Figure 8.8), a factor which is ascribed partly to the low organic content of the Grootdrift sediments, and partly to complications encountered during the lengthy chemical procedure.

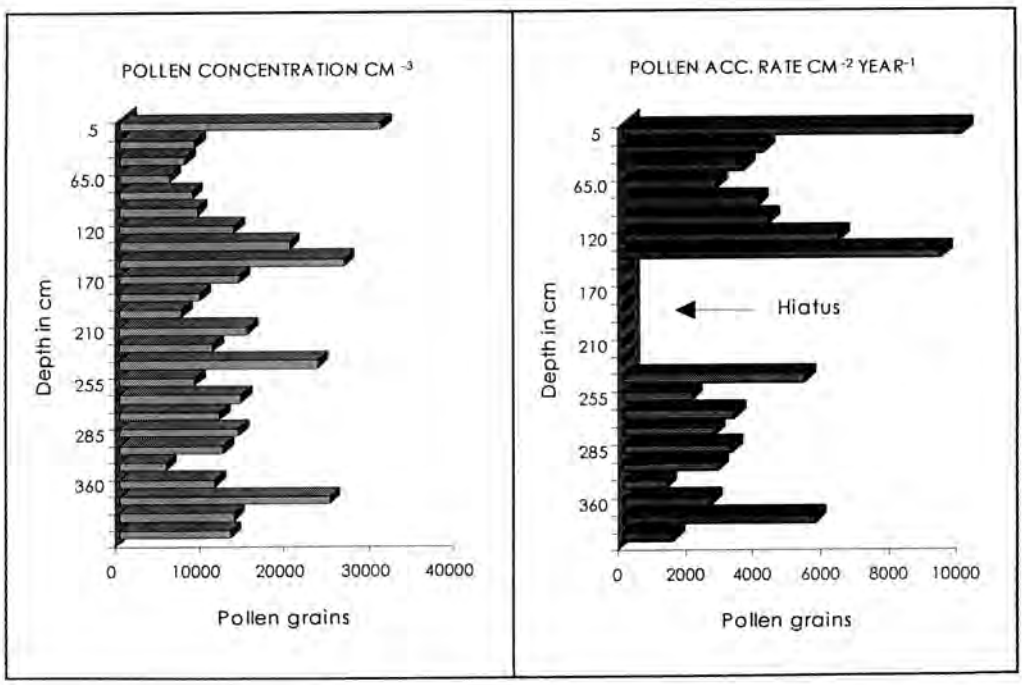


Figure 8.8 Pollen concentration and pollen accumulation rate for GDV1&2. The Hiatus represents a sedimentary discontinuity at Grootdrift.

Despite these methodological problems, preliminary results intimated that significant fluctuations had occurred among many of the major pollen types since 5 550 BP. The results from the fossil pollen analysis of GDV2 are suggestive of a parallel vegetation history to that documented for the equivalent parts of the adjacent core GDV1. This is an encouraging sign, for it confirms that the palynological method of palaeoecological reconstruction used in this instance proves to be reasonably reliable - poor pollen counts notwithstanding. Furthermore, this has allowed for the results from GDV2 to be combined with the preliminary results from GDV1 in a single pollen diagram. In some instances, stratigraphically aligned samples have been combined to produce pollen counts in excess of 400 grains, while in other instances, samples remain depauperate. Pollen counts from the combined cores average at 234 grains per sample. The combined results are presented in the suite of pollen diagrams (Figures 8.9 and 8.10) prefixed by the nomenclature: Grootdrift (GDV1&2).

Significant changes are apparent in the frequencies of many of the major pollen types illustrated in the comprehensive pollen diagram from Grootdrift GDV1&2 (Figure 8.9). The diagram plots the relative proportions of all the identified pollen taxa against stratigraphy and time. The fluctuations in pollen between vegetation categories are better observed by reference to the summary pollen diagram for GDV1&2 (Figure 8.10).

Figure 8.9 Grootdrift (GDV1&2) comprehensive pollen diagram

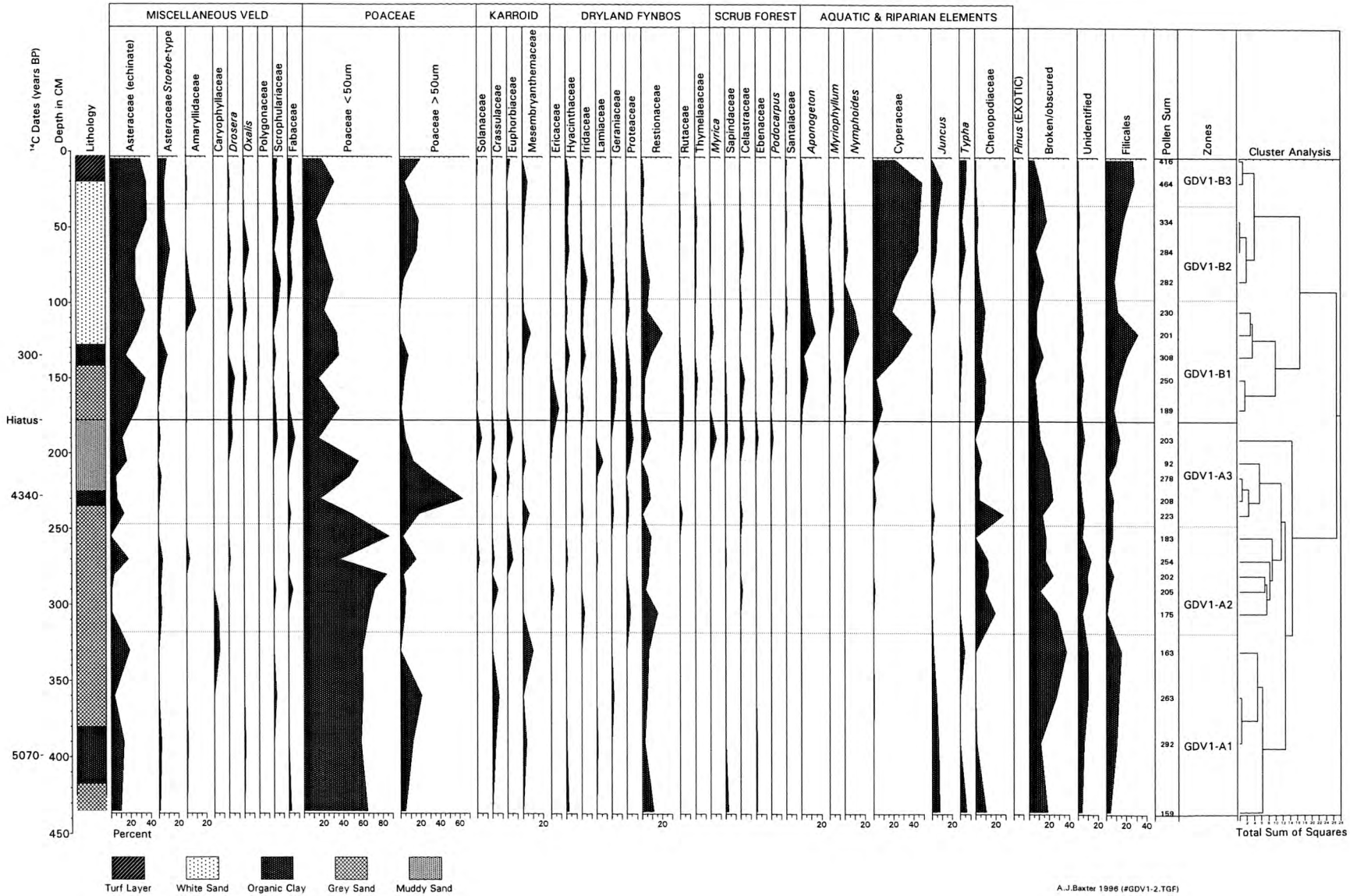
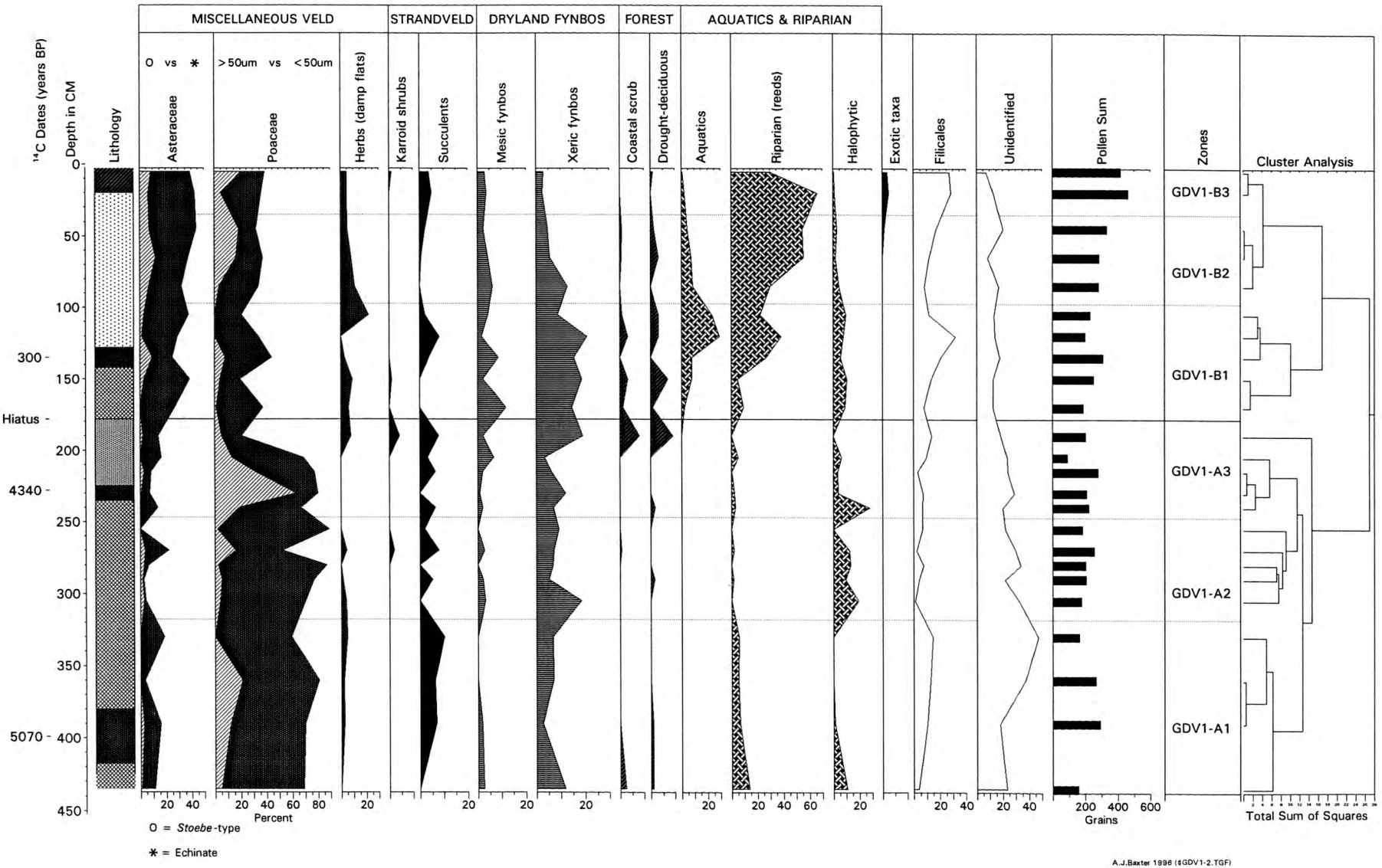


Figure 8.10 Grootdrift (GDV1&2) summary (ECODE) pollen diagram



In Figure 8.10 the taxa have been grouped, according to their ecological provenances (ECODES), into characteristic vegetation categories. For both Figures 8.9 and 8.10, the pollen spectra have been delimited, with the assistance of cluster analysis, into six different pollen assemblage zones. A brief description of each of the pollen zones is presented below, followed by a detailed interpretation of the vegetation history and palaeoenvironmental significance.

Zone GDV1-A1. Pollen preservation and pollen concentration at this depth in the core is poor. Nonetheless, this basal zone, representing the period between 5 550 and *circa* 4 700 BP, displays a reasonably coherent pollen signature from the local hydrophil environment, but is depauperate in terms of terrestrial pollen. The spectra are dominated by Poaceae, especially the smaller sized palynomorphs (< 50 µm). On the basis of morphometric comparisons with modern *Phragmites* pollen, it is tempting to assign many of the smaller sized grass pollen to this taxa - although, of course, this is difficult to substantiate. The presence of saline tolerant taxa, such as *Juncus* and Chenopodiaceae, towards the bottom of the sequence, and the absence of classic fresh water elements such as Cypercaceae and aquatic plants, does suggest that local conditions at the site were perhaps hypersaline. There are no contributions from Afromontane Scrub Forest and, with the exception of Restionaceae, very little Dryland Fynbos pollen is evident. The only significant terrestrial contribution comes from the echinate Asteraceae as well as from Crassulaceae and Mesembryanthemaceae, both karroid succulents.

Zone GDV1-A2. From general appearances, this zone might have been classified along with GDV1-A1, but for the pronounced peak in Chenopodiaceae pollen, and the concomitant fluctuations in grass pollen. Slight increases in the proportion of certain Dryland Fynbos elements such as Proteaceae and, particularly, Restionaceae, are seen to occur at the expense of succulent vegetation.

Zone GDV1-A3. This spectra, which is designated 'pre-colonial' to indicate its age relative to the archaeological record, is presumed to represent the period from about 4 400 BP to the sedimentary hiatus some time after 3 800 BP. The spectra are once again dominated by grass pollen, with frequencies of Poaceae pollen peaking at a maximum of 70 % of the spectra. The other consistently significant element is Chenopodiaceae, which achieves a frequency of 20 % at around 240 cm at approximately the same time as the marked peak in the percentages of large (> 50 µm) Poaceae grains. The tentative appearance of Afromontane Scrub Forest elements, such as *Myrica*, and Dryland Fynbos, towards the top of the zone, is attributed to the juxtaposition of much

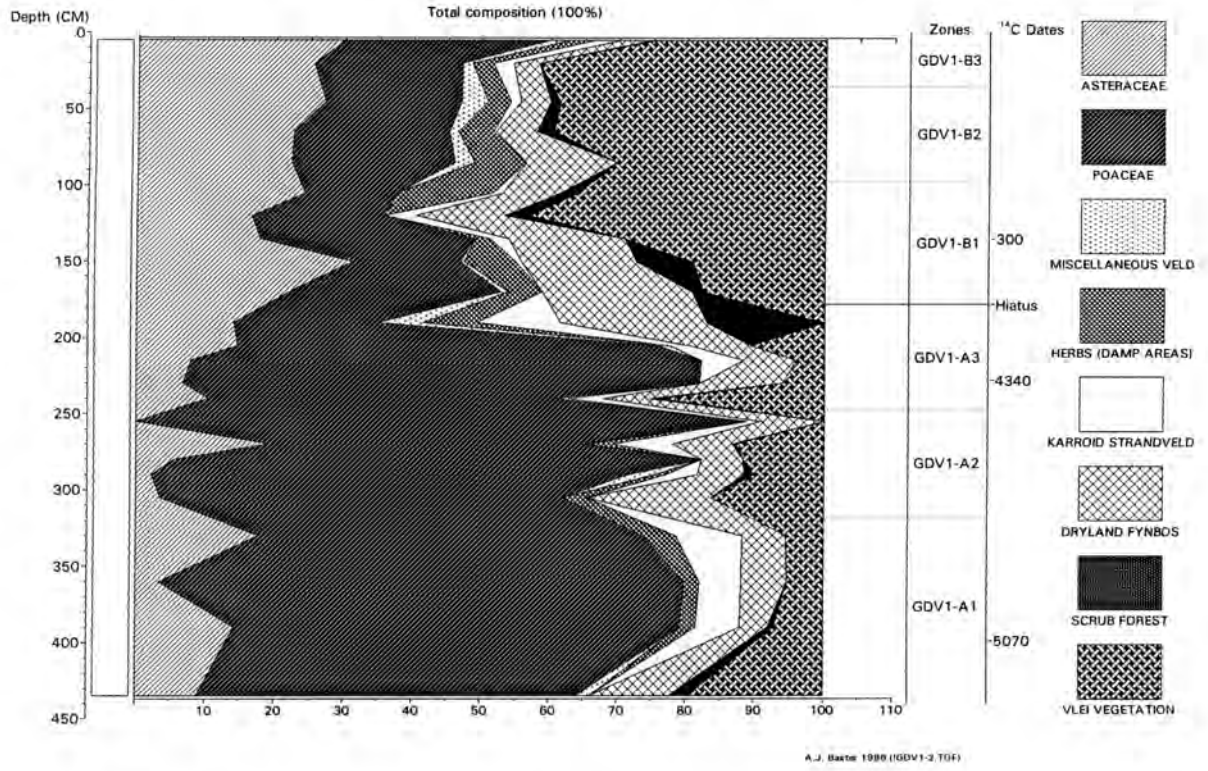
younger sediments on top of GDV1c - a consequence of renewed sedimentation following the hiatus period.

Zone GDV1-B1. Profound changes are observed in the pollen spectra from this zone which approximates the period prior to and during which European settlers first began to colonise the region, following AD 1682 (Sinclair, 1980). Among the hydrophil elements, there is a significant increase in Cyperaceae pollen, while for the first time, truly aquatic taxa such as *Aponogeton* and *Nymphoides* (water lillies) become evident. Poaceae pollen no longer dominate the spectra and their marked decline suggests that a significant environmental alteration occurred at some time during the hiatus period. This observation is supported by the elevated frequencies of terrestrial taxa. Asteraceae pollen, along with a number of characteristic fynbos elements, including Ericaceae, are shown to have increased substantially, following the hiatus. The most significant increases, however, are noted for the pollen from a diverse spectrum of drought-deciduous and coastal scrub taxa. The peak in filicales (fern spores), and the increase in pollen from herbs such as *Drosera* and *Oxalis*, are suggestive of cooler and possibly moister conditions in the extralocal environment for the first time in the sequence.

Zone GDV1-B2. Estimated to represent the time period from *circa* AD 1850 - 1950, this zone is characterised by an exponential increase in the pollen from riparian elements, most notably, the sedges. Although floating aquatic elements show a decline, pollen from the sub-aquatic *Myriophyllum*, persist. Poaceae pollen decline to their lowest proportion in this zone, while Asteraceae pollen reach their maximum. Pollen from fynbos, in particular the Restionaceae and Proteaceae, together with assorted woody scrub elements, appear to be less prolific than the preceding zone, GDV1-B1.

Zone GDV1-B3. This final zone represents approximately contemporary conditions in and around the Grootdrift area of Verlorenvlei. Poaceae pollen percentages moderate at around 30 % of the spectrum, while high percentages of sedge pollen and Asteraceae types comprise most of the balance. Chenopodiaceae is virtually absent, as are the fynbos and woodland elements. Xerophytic Strandveld-type elements, in the form of *Euphorbia* and Mesembryanthemaceae, reappear in the sequence once again. *Stoebe*-type Asteraceae, which includes *Elytropappus*, achieves its highest values in this zone, as does the pollen from the reeds, *Typha* and *Juncus* - although the latter declines at the surface. Several 'weedy' elements, including Scrophulariaceae and the ubiquitous veld element, Fabaceae, are consistently present. Small quantities of *Pinus* pollen indicate the contribution of exotic vegetation to the upper pollen spectra.

Figure 8.11 Grootdrift (GDV1&2) cumulative pollen diagram



8.4.2.1 *Palaeoenvironmental reconstruction of GDV1&2*

The pollen frequencies from GDV1&2 indicate some important changes in the vicinity of Grootdrift during the sedimentation period. (For ease of reference refer also to the cumulative pollen diagram, Figure 8.11). The most obvious is the hiatus at 141 cm which coincides with interpolated vegetation patterns markedly different either side of the non-conformity - an observation confirmed, statistically, by the two principal clusters generated by CONISS and by a departure in the sequence and 'distance' of nearest neighbours (Figure 8.12). The lower spectra of the pollen diagrams, *circa* 5 000 BP, yield a picture of vegetation which is dominated by grasses. Asteraceaous shrubs, Chenopodiaceae and karroid taxa, all indicating xeric terrestrial environments, feature as important secondary elements. It is impossible to determine the species contributing to the high Poaceae percentages but, at the very bottom of the sequence, the Poaceae are dominated by 'small' grains, thought to belong to the saline tolerant reed, *Phragmites australis*. The presence of *Juncus* pollen at this level would seem to support this assertion since the two species share common ecological provenances. *Juncus* and *Phragmites*, in conjunction with Chenopodiaceae, are strongly suggestive of hypersaline conditions, indicating either a seasonal absence of fresh water from the upper catchment or the intrusion of saline water up the Verlorenvlei system. A little higher up

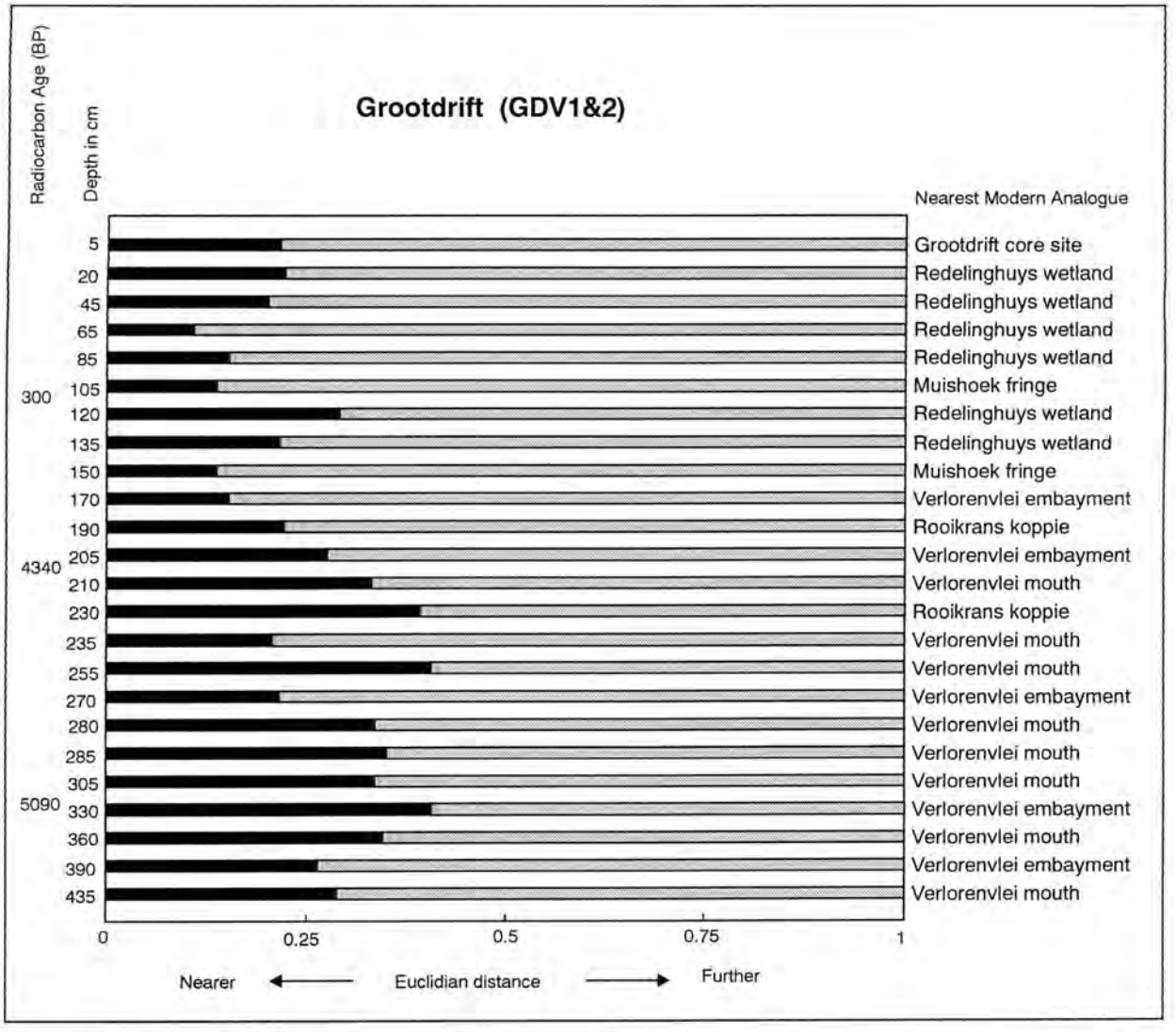


Figure 8.12 Nearest Neighbour Indices (NNIs) for the GDV1&2 pollen spectra. (Refer to Table 6.4 for a description of the analogue sites).

the sequence, a small sedimentary feature has been dated to 4 340 BP and the pollen from this zone demonstrate a pronounced peak in 'large' grass pollen grains with a synchronous peak in Chenopodiaceae pollen. The alteration in the composition and frequency of Poaceae pollen, together with the peak in Chenopodiaceae, is assumed to represent a succession from riverine to full estuarine, possibly even saltmarsh conditions. (Note that *Spartina maritima* and *Sporobolus* spp. pollen both fall into the large category of grass pollen). This interpretation is consistent with a +2.8 m relative sea-level which is dated to around 4 000 BP (Yates *et al.*, 1986; Miller *et al.*, 1993) and which is believed to have transformed the Verlorenvlei into a substantial estuarine/lagoonal embayment at the time. Interestingly, the NNIs for these spectra (Appendix H) suggest that among the closest modern vegetation analogues are those which presently occur at Verlorenvlei mouth and Wadrifsoutpan. This interpretation suggests that an estuarine environment prevailed at Grootdrift, and implies that at some time during the mid-Holocene, sea-levels transgressed the modern Verlorenvlei valley by some 15 km.

The terrestrial signal from the lower part of the diagram suggests that the saltmarsh environment at Grootdrift was surrounded by a catchment in which Restioid Strandveld was prominent, while on the sandstone slopes there appears to have been a vegetation which was strongly xerophytic in character (note the karroid influence from Mesembryanthemaceae, Crassulaceae and Euphorbiaceae). The ratio of Asteraceae to Poaceae pollen is low during this period and, based on environmental interpretations made by Coetzee (1967), this is indicative of semi-aridity. That conditions were xeric is supported by the large proportion of succulents and the predominance of drought-resisting elements among the weak fynbos signal. The relative paucity of elements of Sand Plain Lowland Fynbos and woodland or Afromontane Scrub Forest is intriguing. Either such vegetation was absent from the immediate area due to greater aridity, or the pollen production, dispersal and preservation of constituent taxa are too low to render the vegetation types 'visible'. The NNIs for these lower spectra fail to denote an authentic modern vegetation analogue for the terrestrial vegetation, providing further evidence that conditions may have been more arid than today.

Estuarine conditions at Grootdrift are believed to have prevailed until at least 3 800 BP. The hiatus then obscures the view of the development of the vlei, although at some stage during the late Holocene, sea-level fell sufficiently for the vlei to become non-tidal, following which, terrestrial, fluvial and lacustral, rather than marine processes, appear to have influenced the site. Vegetation reconstruction for the period immediately prior to, and during, 'colonial' settlement, indicates that the hydrology of the site was no longer dominated by saline conditions. The frequencies of Cyperaceae, *Juncus, Typha, Aponogeton, Myriophyllum* and *Nymphoides* combine to suggest that a falling sea-level, with the concomitant retreat of marine conditions westwards, was accompanied by increasing fresh water influence at the site. While Chenopodiaceae decline, they do not disappear altogether, suggesting that saline conditions were maintained not far from Grootdrift. Grass pollen declines markedly by comparison with the period preceding the hiatus, while the surrounding catchment appears to be increasingly characterised by asteraceous fynbos and woody scrub elements. Moisture availability in the extralocal and regional environment would seem to be greater around this time than at any other stage in the sediment sequence. It is hypothesised that fresh water, by now relatively abundant in the vlei, facilitated the expansion of farming and grazing after initial colonial occupation in the early eighteenth century (Sinclair, 1980). The development of the vegetation during the last 250 years or so is not well resolved from the uppermost part of the GDV1 sequence. Despite vigorous counting in these low-organic, sandy levels, the wide subsampling interval (15 cm) has compromised any meaningful interpretation of the sequential vegetation history at a time when significant

human interaction in the landscape is believed to have occurred. The presence of *Pinus* pollen and the increased percentages of *Stoebe*-type, Fabaceae and Scrophulariaceae at the top of the sequence merely confirms the visible pattern of human-induced disturbances among the sensitive environments of the contemporary Sandveld.

8.4.3 The Grootdrift (GDV4) pollen diagram

Among the possible scenarios which are postulated to have accounted for the sudden sedimentary change at 1.28 m in GDV1, and the subsequent rapidity of sandy sedimentation, anthropogenic disturbance within the riparian zone provides both a plausible explanation and a testable hypothesis. With the arrival of colonial agro-pastoralists in the Verlorenvlei area *circa* AD 1700, selective overgrazing by domestic stock, trampling and agricultural clearance are likely to have exacerbated the rate of wind erosion (Lancaster, 1986) - thereby provoking mass encroachment of unconsolidated sand into the vlei from the surrounding slopes. In this regard, it is of interest to note that sandy infill appears only in cores taken from near the margins of the vlei, viz: GDV1 and GDV7. In contrast, cores such as GDV4, derived from near the centre of the vlei, reveal a sequence of slow, steady organic accumulation since the dated marker lens at ± 300 BP.

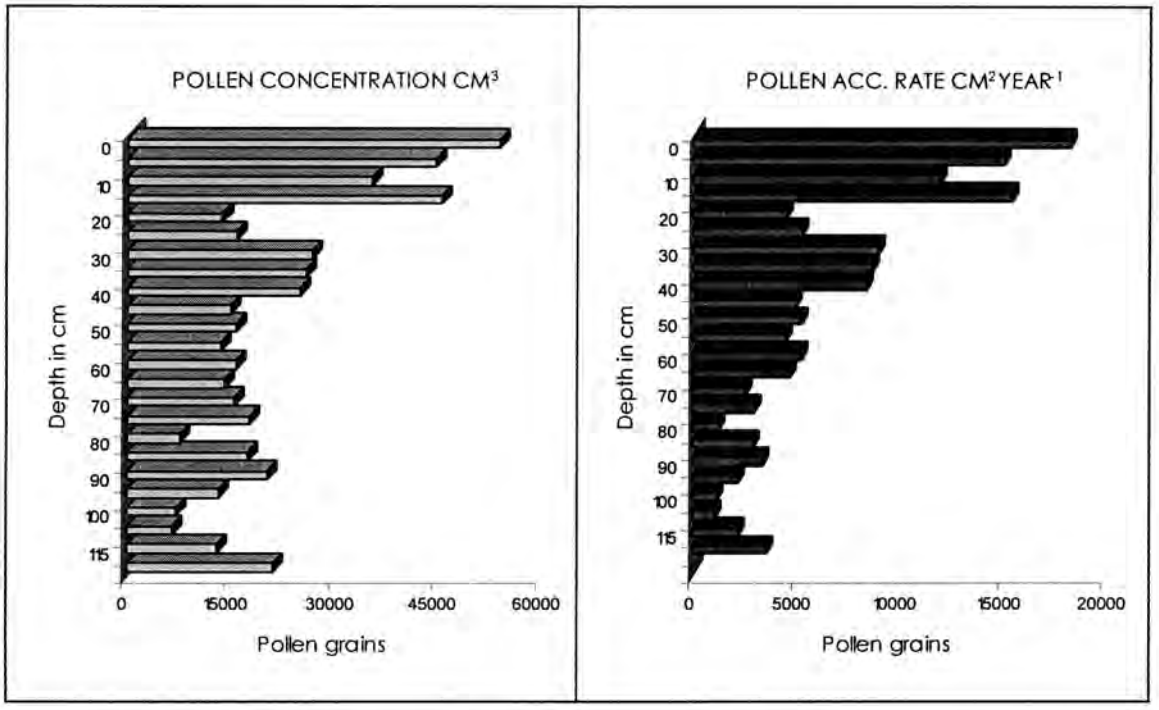


Figure 8.13 Pollen concentration and pollen accumulation rate for GDV4. The steep increase in the rate of pollen accumulation at the site is synchronous with the development of a hydrosere succession at the site - see text for details.

The critical test of this 'human impact' hypothesis is contingent on the analysis of recently accumulated fossil pollen contained within the Grootdrift sediments. Since the sterile sands towards the top of GDV1 demonstrate poor pollen concentration, it was decided to shift the focus of attention to the contemporaneous sediments from the organic-rich GDV4 vibracore. The laminated nature of the lacustrine, clay-rich sediments contained in the uppermost 1.20 m of GDV4, presented an ideal opportunity to conduct a high-resolution pollen study of the local vegetation history since the onset of colonial expansion into the Sandveld region. A total of 24 subsamples were selected at intervals of 5 cm from GDV4 and prepared according to the revised method for clay and mineral-rich samples (Appendix C). The application of heavy mineral separation techniques is credited, in part, with the improved levels of pollen concentration observed from GDV4, which are almost double those of GDV1 (Figure 8.13), averaging around 21 x 10^3 cm^{-3}. Pollen counts fluctuate between 350 and 750 grains per sample, a factor which is expected to contribute to improved levels of statistical reliability of the GDV4 results.

A set of pollen diagrams has been produced for GDV4 (figures 8.14 - 8.16). The comprehensive pollen diagram (Figure 8.14) plots the frequencies of all the identifiable pollen against core stratigraphy and depositional time, while the summary pollen diagram (Figure 8.15) illustrates the pollen taxa grouped according to their ECODES. With reference to the summary pollen diagram, it is clear that the spectra display a significant bias towards the pollen of local wetland indicators. It is speculated that the more sensitive terrestrial indicators, such as the Strandveld and fynbos, may have been diluted by the abundance of prolific pollen-producing vlei indicators. Nonetheless, it remains possible to determine, through time, a number of synchronous community trends across the pollen spectra of the terrestrial indicators, by statistically deflating the significance of the local hydrophil pollen in the pollen sum. This was achieved by calculating the proportion of terrestrial pollen as a function of the total pollen sum less aquatics and unidentifiables. Cluster analysis has separated the diagram into two primary pollen assemblage zones and, using this division as a basis, two additional subsidiary pollen zones have been identified subjectively.

Zone GDV4-A1. The earliest zone, GDV4-A1, reveals the pollen signature of Verlorenvlei immediately after sedimentation resumed following the hiatus at Grootdrift. Pollen preservation is good and the spectra intimate that Poaceae were ubiquitous and far more abundant at this time than the contemporary distribution of grasses. Terrestrial taxa are characteristically diverse and include Proteaceae, Restionaceae and geophytes, typical fynbos elements, and karroid elements such as Aizoaceae and Anacardiaceae. Chenopodiaceae achieve maximum levels in this zone while the

Figure 8.14 Grootdrift (GDV4) comprehensive pollen diagram

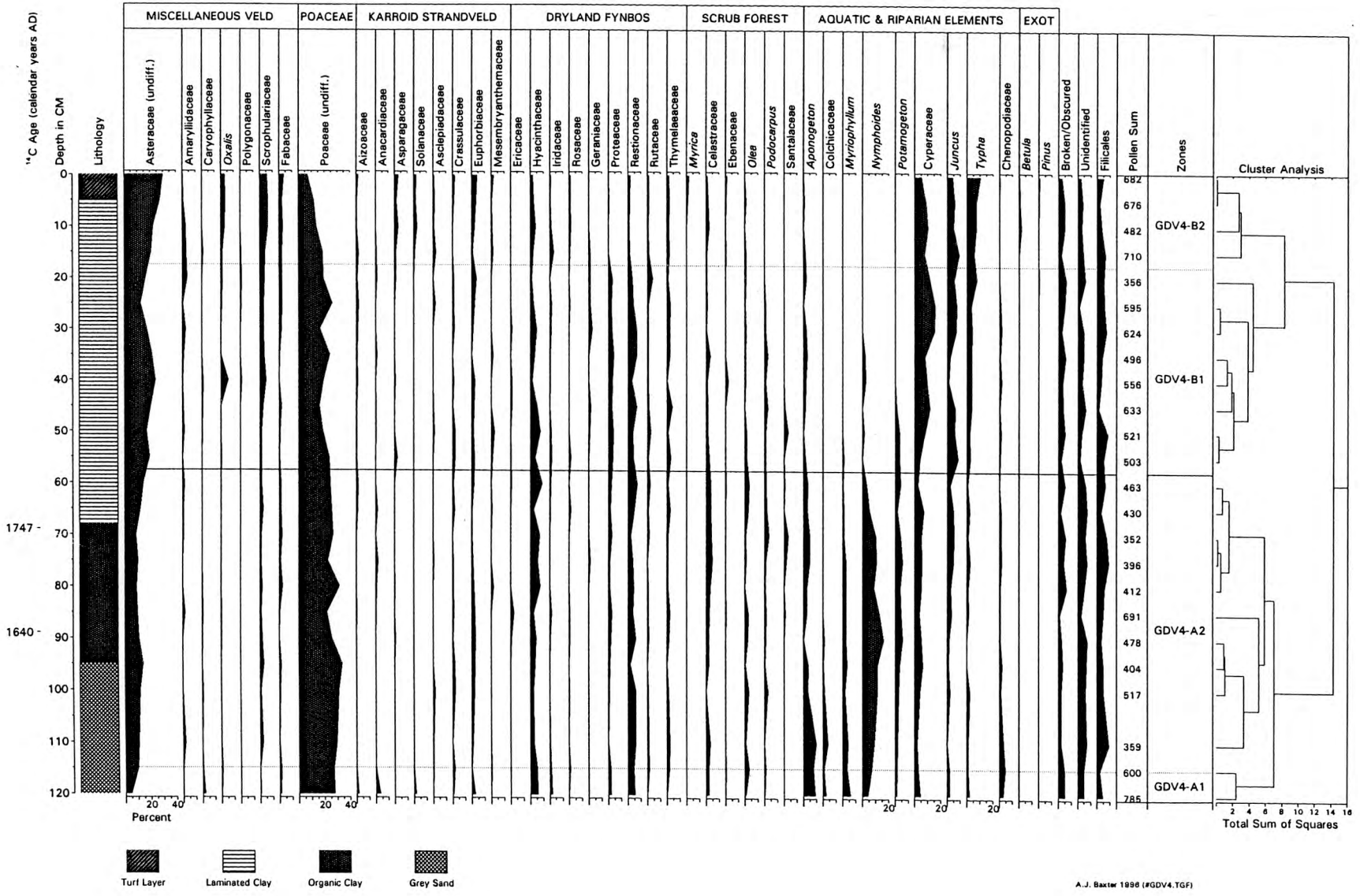
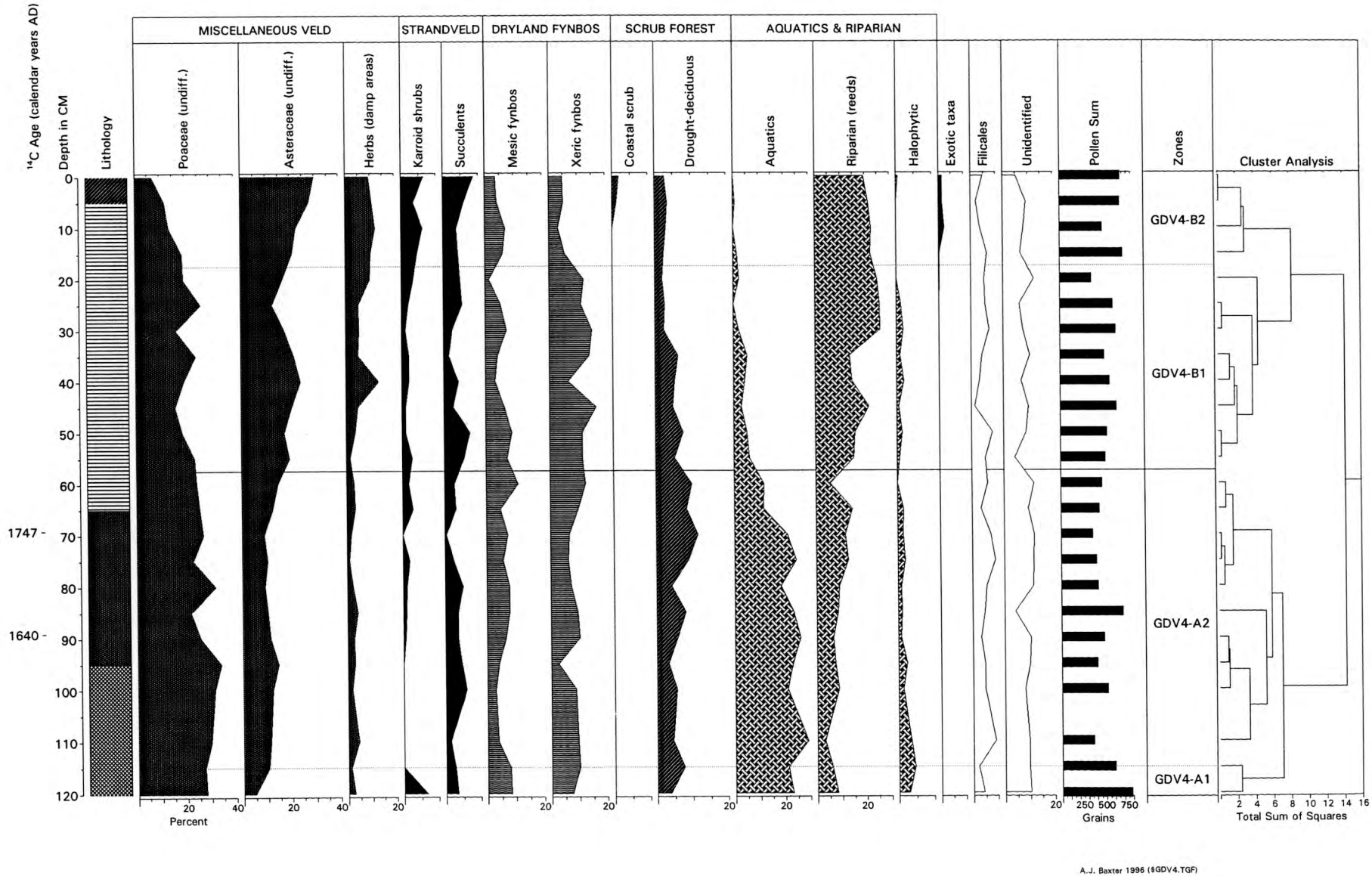


Figure 8.15 Grootdrift (GDV4) summary (ECODE) pollen diagram



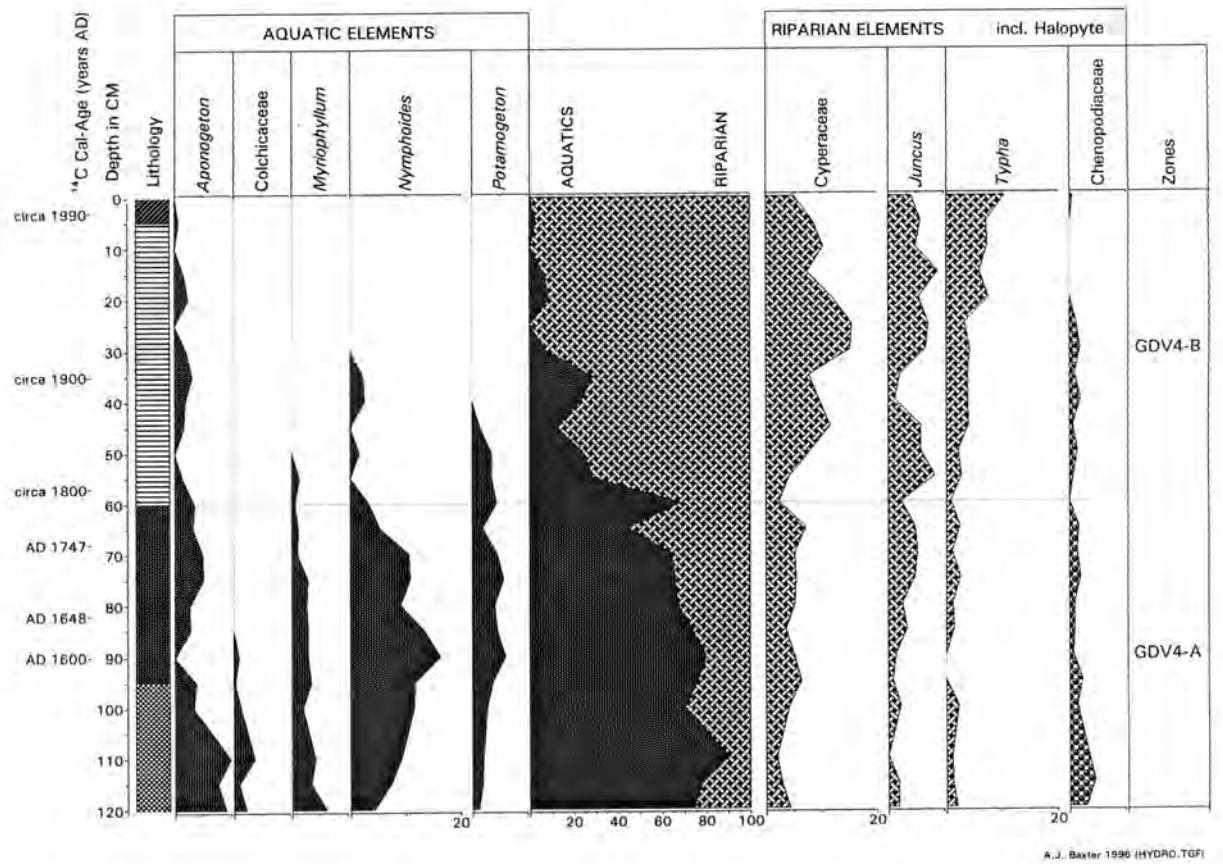
Asteraceae are at a minimum in the sequence. In consideration of the riparian and semi-aquatic pollen, most elements are perceived to be consistent with the results gained from complimentary levels in GDV1&2. The most notable feature of zone GDV4-A1 is the predominance of aquatic vegetation, in particular, *Aponogeton*.

Zone GDV4-A2. This zone coincides with the period of colonial expansion into the Sandveld region. The base of zone GDV4-A2, at a depth of 110 - 115 cm, represents the period immediately prior to the arrival of colonial settlers in the area (*circa* AD 1500 - 1600). A calibrated radiocarbon date of AD 1747, at around 70 cm, is coincident with the period during which European colonisation spread to Verlorenvlei. The zone is characterised in particular by the subtle yet consistently progressive decline in the abundance of Poaceae pollen. Similarly, the frequency of Chenopodiaceae continues to diminish, while the karroid shrubs, such as those represented in Aizoaceae and Anacardiaceae, are replaced increasingly by succulent taxa such as Crassulaceae and Euphorbiaceae. The fynbos signature indicates a respectable contribution from the geophytes, including lilies. Among the woody taxa, noteworthy contributions are made by Celastraceae, among others. Nymphoides (water lilies) increase dramatically to dominate the aquatic pollen spectra. Pollen from emergent reeds including *Juncus* and sedges also reveal subtle increases.

Zone GDV4-B1. Zone GDV4-B1 is assumed to represent the period of post-colonial agro-pastoralsim. This zone is particularly significant in that it portrays a number of synchronous changes across the pollen spectra. The terrestrial component is distinguished by appreciable increases in the pollen of Asteraceae, Scrophulariaceae and *Oxalis* spp. Similar increases are portrayed by the riparian elements *Typha* and *Juncus*, while Cyperaceae pollen is seen to increase dramatically. Concomitantly, the aquatic vegetation reveals a substantial decline, and it seems evident that a significant change must have occurred in Verlorenvlei around this time (*vide*: *Nymphoides* and *Potamogeton*). Drought-deciduous woody elements, including Celastraceae show a pronounced proportional decline, although levels of diversity among this category remain surprisingly high.

Zone GDV4-B2. The uppermost zone, GDV4-B2, extends from a depth of about 20 cm to the current surface level and is considered to be modern which, by the author's definition, would suggest that it accumulated at some time during the last 50 years. (assuming consistent depositional rates in the centre of the vlei). The pollen from Asteraceae increase exponentially to reach maximum proportions, while Poaceae decline rapidly to the their lowest levels at the top of the sequence. The frequencies of

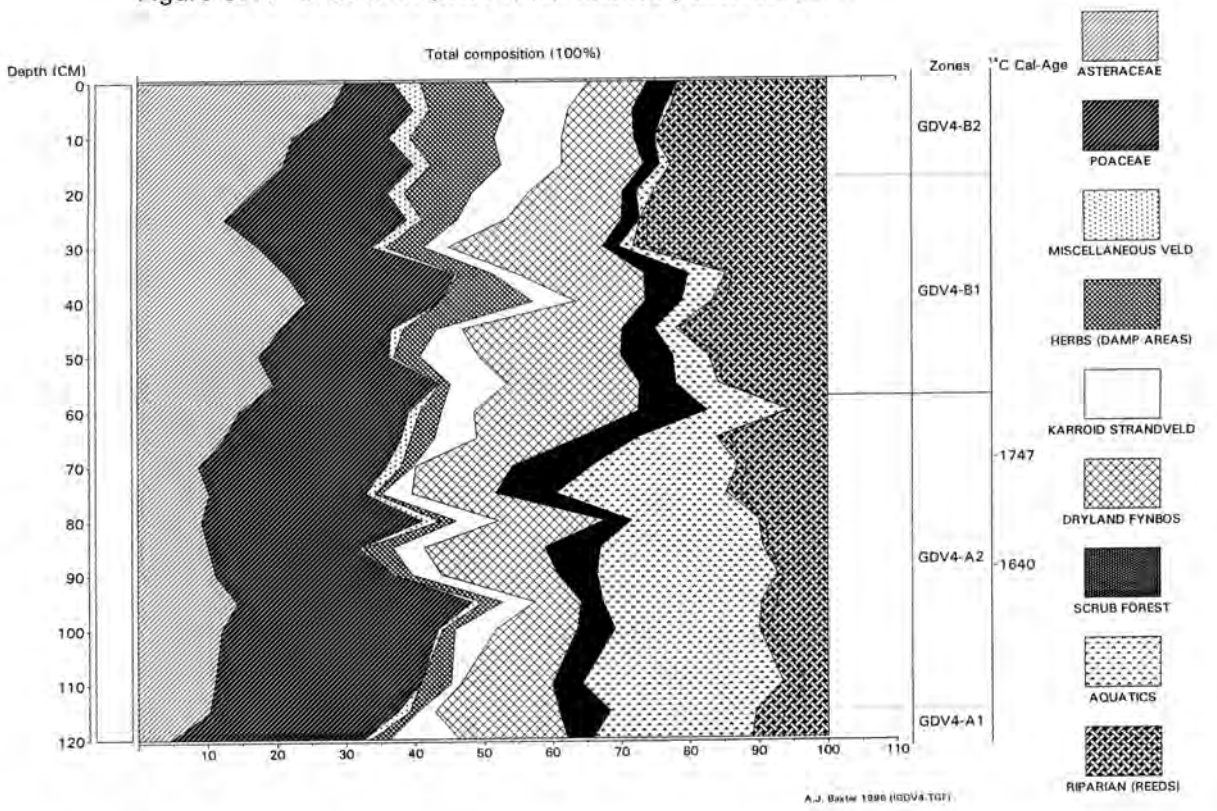
Figure 8.16 Grootdrift (GDV4) hydrosere succession



Oxalis and Scrophulariaceae are seen to mirror the pervasive increase in Asteraceae pollen. Zone GDV4-B2 is further distinguished by the synchronous decline in the pollen of a number of fynbos elements, most notably Restionaceae, Proteaceae and Ericaceae. Non-palatable karroid succulents of the family Euphorbiaceae are seen to capitalize on the apparent fynbos demise. With the exception of the Chenopodiaceae, all of the riparian and semi-aquatic indicators proliferate, with the increase in *Typha* being the most pronounced. The pollen produced by true aquatic indicators all but disappear by the present day.

Mindful of the fact that alterations in the pattern of local vlei vegetation at Verlorenvlei are likely to reflect environmental changes which are independent of the terrestrial environment (Arts and Leuven, 1988; van Groenendael *et al.*, 1993), and given the sensitive nature of the local hydrological regime and the fluctuating environmental identity of the Verlorenvlei system, it was decided to construct a third pollen diagram (Figure 8.16) to investigate specifically the vegetation history of aquatic and riparian elements at Grootdrift. The improved resolution of the pollen diagram (brought about through the omission of extraneous terrestrial pollen) reveals the development of a pronounced hydrosere succession at Grootdrift during the sedimentation period.

Figure 8.17 Grootdrift (GDV4) cumulative pollen diagram



Towards the bottom of the sequence, aquatic elements such as *Aponogeton* and *Nymphoides* are seen to dominate the spectra. Sometime after AD 1747, emergent reeds including Cyperaceae and *Juncus* begin to appear in greater proportions and finally, by the top of the sequence, *Typha* are seen to dominate - as they do at the site today. The composite graph in the centre of the pollen diagram clearly illustrates the progressive nature of the vegetation succession at Grootdrift. It is acknowledged that Poaceae (grasses) are an important constituent of the Grootdrift GDV4 pollen spectra, yet without re-evaluation of the grass palynomorphs, it is not known to what extent the composition of the Poaceae can be ascribed to either terrestrial grasses or the emergent aquatic reed, *Phragmites australis*.

8.4.3.1 *Palaeolimnological reconstruction of GDV4*

When viewed together, the comprehensive and summary pollen diagrams from GDV4 reveal a variety of changes in the composition of regional and extralocal vegetation but, as with GDV1&2, the most significant changes are seen to occur among the local hydrophil elements. The sequential fluctuations, apparent within the pollen data (for ease of reference refer to Figure 8.17), suggest that the vegetation ecology of the

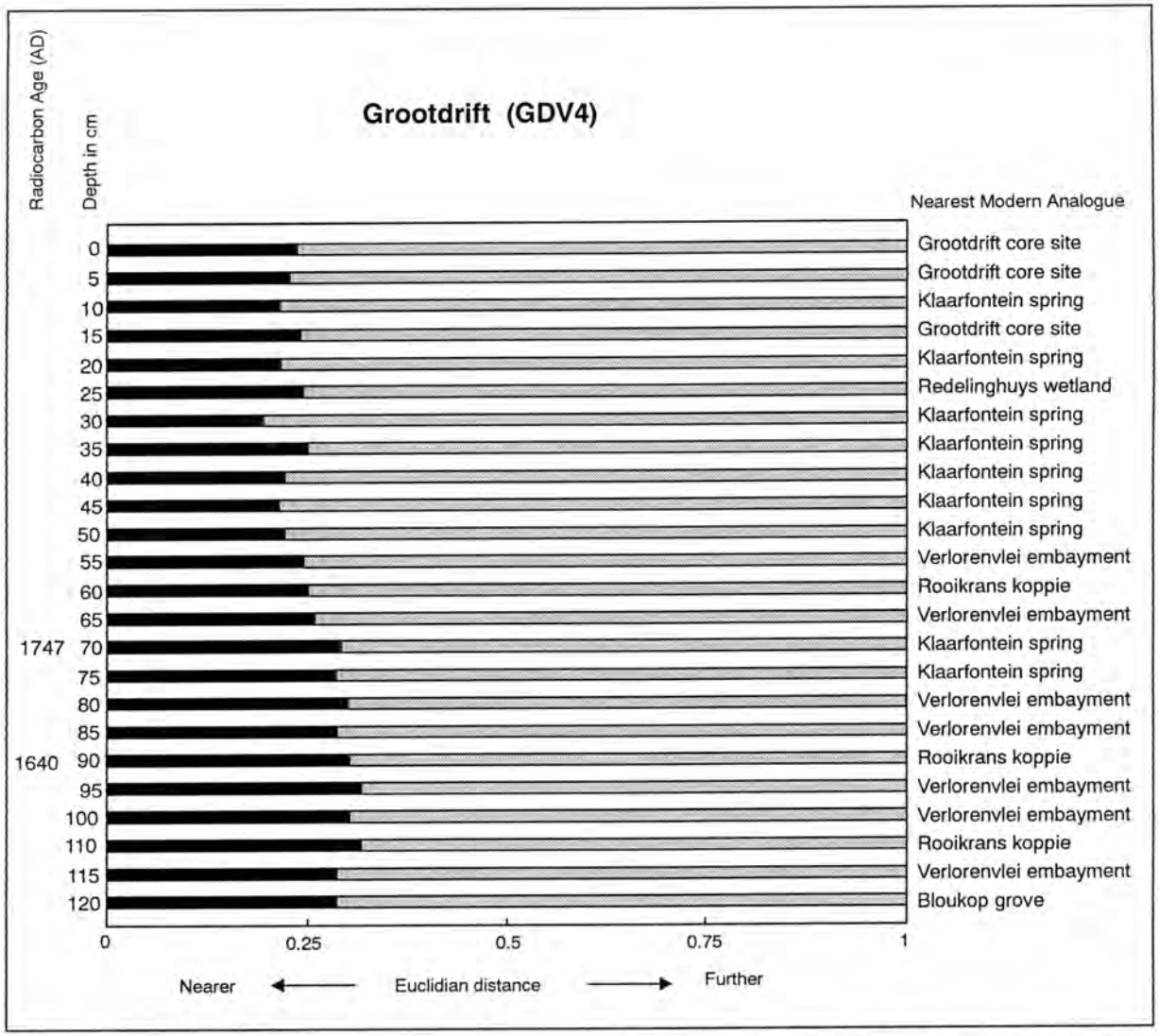


Figure 8.18 Nearest Neighbour Indices (NNIs) for the GDV4 pollen spectra. (Refer to Table 6.4 for a description of the analogue sites).

Grootdrift site has endured a pronounced transformation during the course of the past ± 500 years. Figure 8.18 plots the NNIs for GDV4 and suggests that at various times in the past Grootdrift may have resembled parts of the lower system such as the Verlorenvlei Farm embayment and the Verlorenvlei mouth. It may be that the pre-colonial riverine lacustrine (open water) phase at Grootdrift was an expression of cooler and moister climates in the southwestern Cape in response to the Little Ice Age - the most recent in a series of minor neoglacial expansions since the Last Glacial Maximum (Tyson, 1986). However, the scant evidence from tree-ring studies of *Widdringtonia cedarbergensis* in the nearby Cederberg range does not offer a convincing interpretation in support of significant climatic deviation during this period of sedimentation (Dunwiddie and LaMarche, 1980). Instead, the envisaged adjustment in limnology and vegetation ecology is ascribed largely to the consequence of progressive anthropogenic interactions in and around the wetland system, and the systematic elimination of indigenous mammalian fauna in the Sandveld.

The pollen spectra of the earliest zone, GDV4-A1, precede the arrival of European colonists in the Sandveld. The pollen spectra suggest that the local environment at this time was characterised by a shallow, fresh water embayment, an environment capable of supporting the submerged macrophyte, *Myriophyllum spicatum* ('Parrot's Feather'). This species prefers slow-flowing water up to about 2 m deep, where it is able to root in the muddy substrata (Robertson, 1980). The abundance of other typical fresh water indicators including, *Aponogeton* spp. (the colloquial 'wateruintjie'), *Potamogeton pectinatus* ('Sago Pondweed'), and *Nymphoides indica* (the yellow water lily), lend additional support to the notion that there was abundant fresh water that lasted at least for the duration of the winter months (Bond and Goldblatt, 1984). As is presently the case at Verlorenvlei, extreme summer evaporation is likely to have induced seasonal conditions of higher salinity, especially in stagnant riverine pools and along exposed mud flats, and the presence of Chenopodiaceae pollen also suggests that halophytic elements, typical of saltmarsh environments, such as *Limonium, Salicornia* and *Chenolea* species, were present among the riparian component. Of the reed elements, it is possible, given the high levels of grass pollen in this zone, that *Phragmites australis* might have occupied the fringes of the embayment. *Phragmites* is able to endure fairly drastic seasonal fluctuations in the water table and is also resilient to changes in salinity (Grindley and Grindley, 1987). By comparison, the low proportion of *Typha latifolia*, could be a consequence of the intolerance of the reed to salinity as well as to its dependence on a more stable water table (Noble and Hemens, 1978).

It is not improbable that the foraging action of large indigenous mammals, including *Hippopotamus amphibius* (hippos) and *Loxodonta africana* (elephant) would have had a profound effect on the riparian and semi-aquatic vegetation in the pre-colonial landscape (Field, 1970; Kingdon, 1979). Hippos, in particular, are known to play a vital role in the translocation of nutrients from land to water via their propensity to graze on land and then to excrete in their aquatic environment (Taylor, 1980). As prodigious consumers of sedges, hygrophilous grasses, *Typha* and *Potamogeton*, hippos also contribute to the regulation and maintenance of riparian vegetation by establishing grazing-mosaics, interlinked by open channels and access paths (Kingdon, 1979).

Throughout zone GDV4-A2, the Grootdrift site appears to exist, predominantly, as an open aquatic environment. There are few changes of any substance noted from the terrestrial components, and the regional interpretation is one of grassy Dryland Fynbos on the lower slopes with succulents such as *Carpobrotus* and *Ruschia* on the shales and Afromontane Scrub Forest taxa, including *Maytenus, Olea* and *Podocarpus* limited to the sandstone koppies and ravines to the south of the site. A marked shift within the

composition of the aquatic flora is indicated by the increase in *Nymphoides indica*, a perennial, seemingly at the expense of *Aponogeton* species. In conjunction with the subtle increase in the proportion of marsh elements, such as *Juncus* and Hyacinthaceae (≈ Liliaceae), the synchronous decline in the abundance of halophytes such as Chenopodiaceae suggests that lentic pools of fresh water may have persisted all year round at the site. This subtle hydrological adjustment and possible change in water chemistry is ascribed to river impoundment following early historical attempts at causeway construction near the mouth of the estuarine lake (Sinclair, 1980), and on the farm Grootdrift.

During the period of rapid sedimentation in GDV1, the contemporaneous zone 'B1', in GDV4, reflects, a pronounced ecological transformation in both the wetland and terrestrial environment. For the first time in the sequence, significant changes occur in the pollen from regional and extralocal vegetation communities. Incriminating evidence for the onset of selective overgrazing and landscape mismanagement characterises the upper half of the pollen diagram. Following the displacement of the indigenous mixed-feeding herbivorous mammals by increasingly large numbers of domestic livestock (Lane, 1980), the stabilizing influence of shallow-rooted grasses and sensitive ground-cover vegetation appears to have been greatly diminished. Throughout the sequence, fynbos and Strandveld are poorly represented although a consistent increase in proteaceous elements and spiny shrubs such as *Protasparagus*, lend support to the concept of deeper-rooted shrub elements replacing overgrazed grasses and trampled lower strata vegetation (Sinclair *et al.*, 1986). A dramatic increase in the proportion of asteraceous pollen, including an abundance of *Stoebe*-type, is indicative here, as elsewhere in the fynbos (Meadows and Sugden, 1991a), of overgrazing, overburning and agricultural clearing. Grass pollen frequencies reach an all time low, whilst the introduction of alien vegetation in the form of *Pinus* is noted in the spectrum. Certain fynbos elements, particularly woody taxa, are seen to demonstrate a paradoxical resilience to the steadily degrading environment. It is postulated that the rocky sandstone outcrops to the south of the vlei provided a natural refuge to Dry Mountain Fynbos, and offered, as they do today, protection against indiscriminate clearing for agriculture.

The reconstruction of the local hydrophil vegetation sequence is equally complex for this time period. Seasonal and permanent fresh water aquatic indicators, formerly ubiquitous in the lower sedimentary sequence, become systematically replaced by vegetation indicative of a more stable water table and permanent marsh-type conditions. While the dominant aquatic *Nymphoides indica* declines steadily and then vanishes altogether, the emergent reed *Juncus* and the communal 'bulrush' *Typha*

latifolia become increasingly abundant. Most notable in the riparian vegetation pollen spectrum is the progressive upsurge in the proportion of Cyperaceae, with likely candidates being the sedges, *Scirpus maritimus*, *Cyperus marginatus* and *C. fastigiatus* (Grindley and Grindley, 1987). By the zone boundary at 20 cm, the pollen spectra are dominated largely by emergent reed elements to the exclusion of other riparian vegetation.

The final and most recent zone, GDV4-B2, is distinguished by contemporaneous fluctuations in both the terrestrial-disturbance indicators and the riparian and semi-aquatic vegetation. The regional pollen spectra from this zone provide convincing evidence for anthropogenic impact within the natural vegetation. The pronounced decline in grass pollen may be attributed to increased grazing pressure from sheep and cattle. The grass decline occurs despite an apparent increase in *Phragmites* pollen at Grootdrift - an assumption based on the increased trend among other compatible emergent reeds. 'Weedy' elements such as *Emex*, *Oxalis*, and *Nemesia*, taxa typically indicative of agriculture, proliferate, while concomitant increases in classic disturbance indicators such as *Stoebe*-type, confirm the established pattern of widespread disturbance. Furthermore, the almost total absence of *Podocarpus* and *Olea* pollen is noted for the first time in the GDV4 spectra. These unique Afromontane Forest elements, long exploited as the only source of local timber, are seen to be systematically replaced by alien tree species, as is evidenced by the presence of *Pinus* and *Betula* pollen.

Among the vlei indicators at the top of the sequence, Cyperaceae, and to a lesser extent, *Juncus*, moderate under the influence of a *Typha* expansion. The presence of lilies and the almost total absence of Chenopodiaceae indicate that the site is now devoid of any saline influence. The total absence of aquatic indicators confirms the succession, at Grootdrift, from a seasonal lacustrine environment to a perennial fresh water marsh.

8.5 The Klaarfontein Spring site

Following the Grootdrift investigation, attention was focused on the Klaarfontein Spring site, located upstream of Grootdrift and slightly removed from the immediate influence of the Verlorenvlei River. From the series of investigative vibracores derived from the springs, a single core, KFN, was retained for analysis. KFN is elevated at 1.9 m amsl and is perched on an alluvial fan some 40 m away from the north bank of Verlorenvlei River.

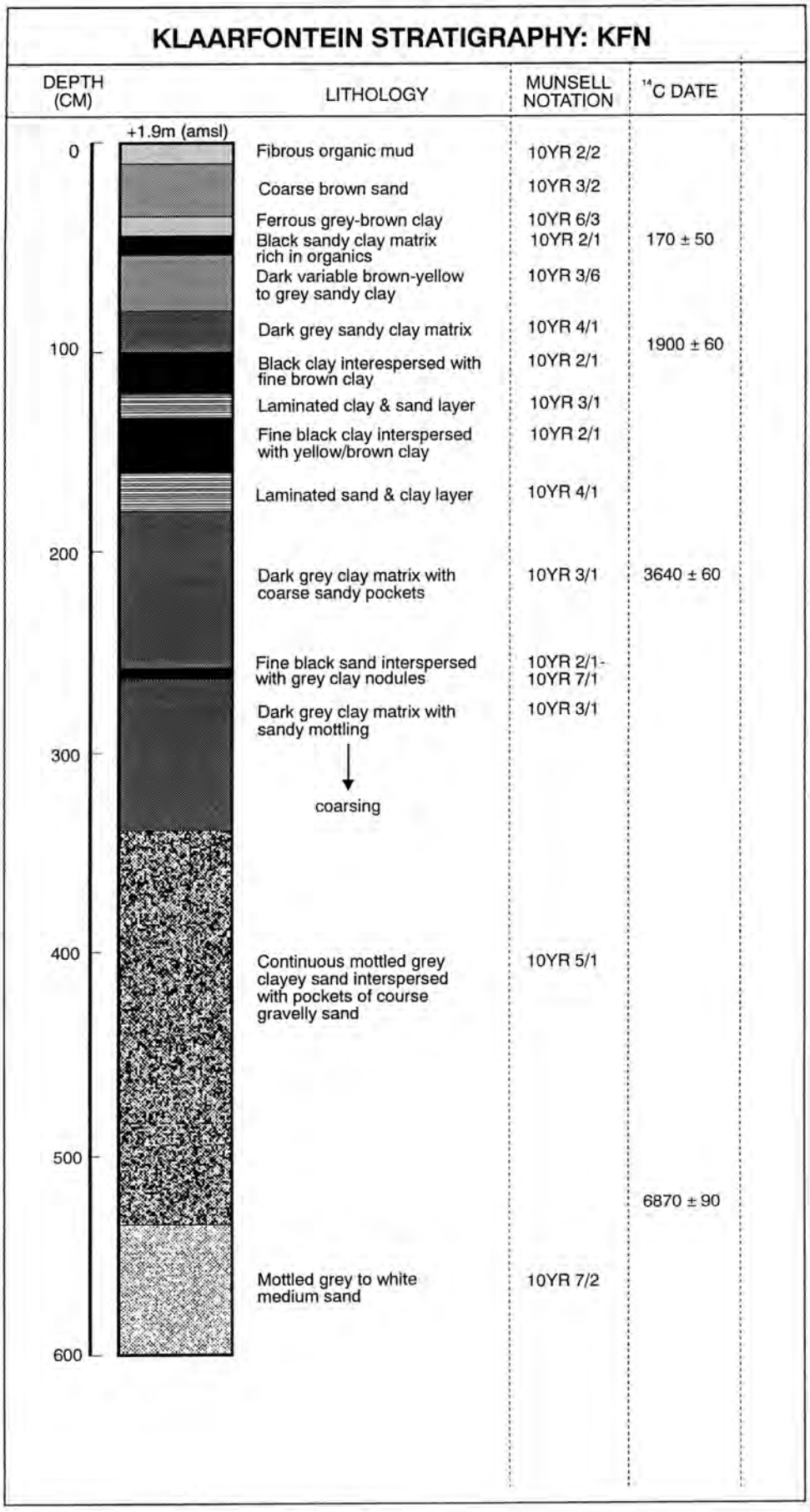


Figure 8.19 Klaarfontein stratigraphy : KFN.

8.5.1 Stratigraphy and chronology

The Klaarfontein vibracore reveals a complex stratigraphy around the spring site and this information is recorded, in detail, in Figure 8.19. Four radiocarbon dates have been secured from organogenic layers in the 5.50 m core. A facies change at a depth of 5.10 m has returned a basal age of 6 870 ± 90 BP (Pta 6148), while distinctive black clay-like layers at 1.95 m, 1.05 m and 0.30 m have produced dates of 3 640 ± 60 BP (Pta 6145), 1 900 ± 60 BP (Pta 6146) and 170 ± 50 BP (Pta 6150), respectively. The lower half of the core, as with the Grootdrift transect cores, records little variation in the physical structures. Between 5.50 and 3.40 m, sediments are characterised by medium-grained, rounded, quartzitic sand of varying colour (grey to white), interspersed with occasional pockets of gravel and clay. By comparison, the diverse stratigraphy of the upper half of the core is suggestive of greater variability among the sedimentary processes. Between 3.40 m and the surface, thirteen distinct stratigraphic horizons are visible in the sedimentary profile and these are mostly characterised by alternating episodes of sand, sandy-clay and laminated mud layers.

Table 8.2 records the sequence of sediment accumulation at Klaarfontein and suggests that the sedimentation rate, between 6 870 BP and 3 640 BP, is similar to that recorded in the basal sequence of the Grootdrift cores (ie in the order of 1 mm $year^{-1}$). The Klaarfontein data also highlight an aberration in the sediment accumulation rates between 3 640 BP and 170 BP. During this period, sedimentation appears to have slowed considerably. A more likely interpretation is that sediments have been removed from the spring sequence through erosional processes. The possibility of a sedimentary hiatus at Klaarfontein during the late mid-Holocene is consistent with the sedimentary record from Grootdrift - except that the date of 1 900 BP poses something of an enigma, since it falls in the middle of the supposed Grootdrift hiatus. As a result of the improved temporal resolution gained from KFN, the timing of sedimentation in the proximal reaches of Verlorenvlei can thus be re-evaluated. A possible explanation is that more than one sedimentary discontinuity occurred in the upper system during the period 3 600 to 300 BP. On the basis of the KFN record, it is speculated that at least one hiatus occurred between 3 640 BP and 1 900 BP and that another took place between 1 900 BP and 300 BP. The sediments dated to around 1 900 BP are thus interpreted to be part of an 'island' of sedimentation that occurred during the late-mid-Holocene. The accumulation rate of sediments at the surface of KFN is consistent with those recorded from the surface of GDV4.

DEPTH (IN CM)	INFERRED TIME INTERVAL	ACCUMULATION RATE
30 - 0	170 radiocarbon years	1.8 mm yr^{-1}
105 - 30	1730 radiocarbon years	**0.4 mm yr^{-1}**
195 - 105	1740 radiocarbon years	**0.5 mm yr^{-1}**
510 - 195	3230 radiocarbon years	1.0 mm yr^{-1}

Table 8.2 Sediment accumulation rates at Klaarfontein (KFN). Values highlighted in black indicate a reduced sedimentation rate.

Despite the spatial and locational differences that distinguish the sites, an attempt has been made to seek correlations between the stratigraphy of KFN and the stratigraphy of the Grootdrift cores. A distinctive black mud and clay layer at 2.60 m in KFN was not dated but is hypothesised to be contemporaneous with the organic marker at similar height amsl observed in GDV1 - GDV5 and dated to 4 340 BP. If indeed sediments during this time period were accumulating at 1 mm $year^{-1}$ at Klaarfontein, then by extrapolation the age of the organic layer would be 4 370 BP - remarkably close to the date derived from Grootdrift. The uppermost organic-rich black clay-layer at Klaarfontein, dated to 170 BP, is believed to represent a spatial extension of the upper organic pulse first recorded in the Grootdrift transect and dated to 200 BP in GDV4. If this is the case, it suggests that lacustrine conditions prevailed at Klaarfontein, as they appear to have done at Grootdrift, as recently as AD 1680 (calendar years calibrated according to Stuiver and Becker (1993)). Since KFN has produced both a longer and more consistent sedimentary record than any of the Grootdrift cores, it was felt that a detailed palynological investigation would aid the stratigraphic and palaeolimnological interpretation of the upper Verlorenvlei system as well as complimenting the preliminary regional pollen data derived from GDV1&2.

8.5.2 The Klaarfontein (KFN) pollen diagrams

Pollen analysis of the KFN core proceeded in two phases. An initial exploratory investigation was performed at a wide subsampling interval every 50 cm along the length of the core. Following this preliminary analysis, additional subsamples were derived every 10 cm in the stratigraphically-complex upper half of the core, and every 25 cm from the stratigraphically-consistent lower half of the core. Organic matter content was generally low (averaging 5 mol mg^{-1}), except for samples derived at around 135 cm, where levels rose to 14 mol mg^{-1} (Figure 8.20). Refinements in the chemical concentration procedure, most notably the application of sodium pyrophosphate and zinc chloride (in preference to strong acids such as hydroflouric acid), appear to have

reduced the potential for corrosion among the palynomorphs. Pollen concentrations are seen to mirror the increase in organic matter at 135 cm, achieving maximum values of 38 x 10^3 cm^{-3} at this level - just over double the average for the rest of the core (Figure 8.20). Owing to the uncertainty regarding sedimentation rates higher up the sequence, pollen accumulation rates have not been plotted for KFN.

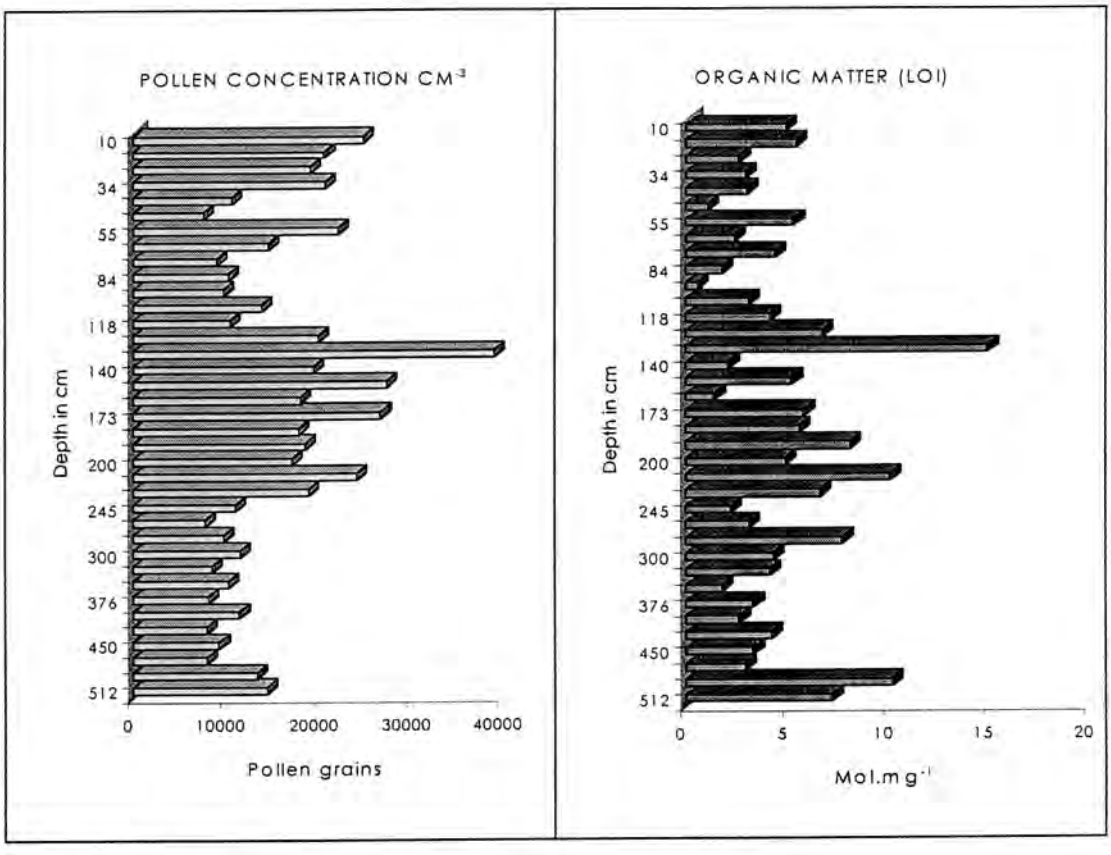


Figure 8.20 Pollen concentration and organic matter (LOI) values for KFN.

The analysis of 37 pollen spectra from KFN yields a complex picture of vegetation and environmental change at the site. The comprehensive pollen diagram (Figure 8.21) has been divided into two major pollen assemblage zones on the basis of cluster analysis. However, to aid in the vegetation description, four additional subzones have been included for the complex uppermost pollen assemblage zone. The summary pollen diagram from KFN (Figure 8.22) illustrates the spectra graphed in accordance with their ECODES. In an effort to overcome the dominant influence of local wetland pollen, the terrestrial taxa have been graphed as a function of the total pollen sum (presented on the left hand side of Figure 8.21) less the combined contribution made by the local aquatic and riparian elements.

Figure 8.21 Klaarfontein (KFN) comprehensive pollen diagram

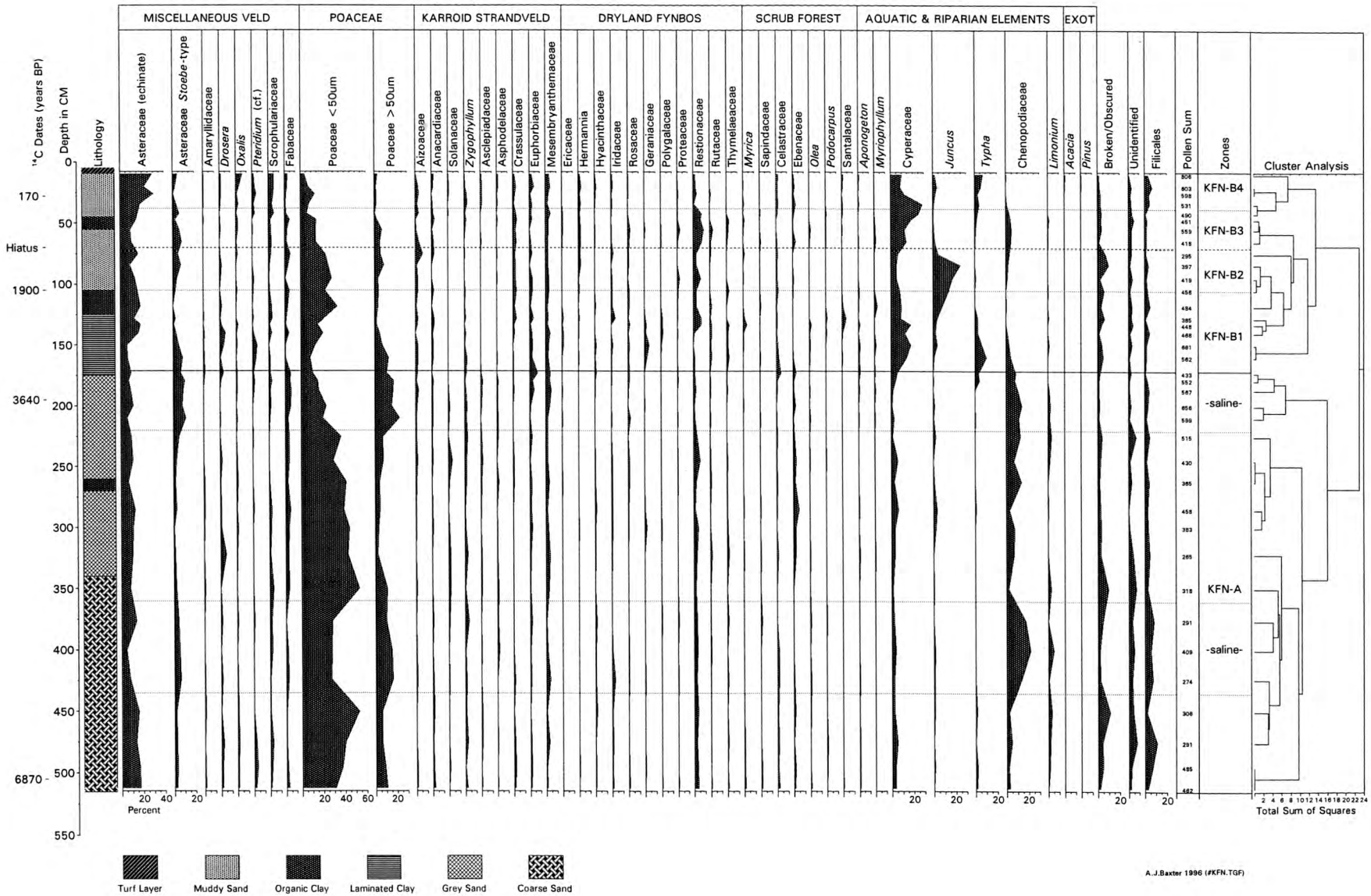
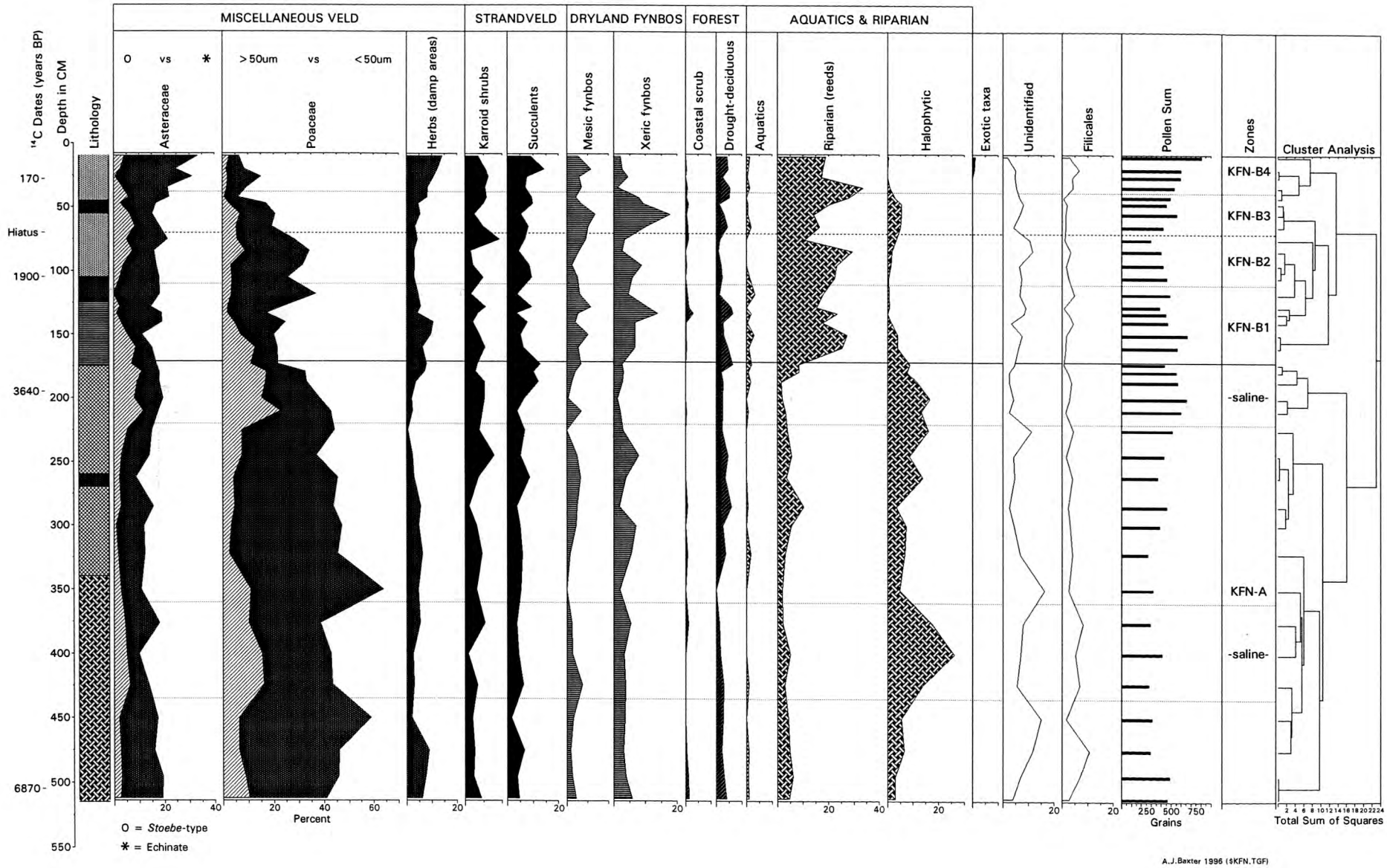


Figure 8.22 Klaarfontein (KFN) summary (ECODE) pollen diagram



Zone KFN-A. Extending from 510 cm to 175 cm, this zone spans the period from 6 800 BP to *circa* 3 450 BP (this date inferred on the basis of a consistent sedimentation rate of 1 mm year^{-1}) and includes the oldest deposits thus far secured from the Verlorenvlei wetlands. A radiocarbon date at 195 cm dates a darker horizon to 3 640 ± 60 BP (Pta 6145). As with the basal deposits of GDV1&2, these spectra are extremely poor in both concentration and condition of pollen. Given the evidence from GDV1&2, it is not surprising that the KFN-A spectra are also dominated by pollen from the Poaceae and Asteraceae families. Throughout the sequence the Poaceae are generally comprised of smaller-grained palynomorphs (< 50 μm) which may include the pollen of *Phragmites*.

Two major diagnostic pollen-events punctuate the otherwise consistent assemblage zone of KFN-A. At around 400 cm a marked increase is evident among the pollen of the Chenopodiaceae, Poaceae (in particular, palynomorphs of the larger variety, viz: > 50 μm), and *Stoebe*-type Asteraceae. The pollen from Plumbaginaceae, probably *Limonium*, peaks synchronously with the Chenopodiaceae, while smaller sized grass palynomorphs (< 50 μm) decline. Sometime after 4 500 BP, the Chenopodiaceae moderate and the spectra revert back to proportions broadly similar to those at the base of the sequence. A subtle increase in Chenopodiaceae, *Juncus* and Cyperaceae coincides with the organic layer at 260 cm. There is little discernible change in the spectra until about 4 000 BP where, at 200 cm, the large Poaceae grains, *Stoebe*-type Asteraceae and, to a lesser extent Chenopodiaceae and *Limonium*, reach a peak once again - indicating, perhaps, a repeat of the pattern observed from lower in the sequence at 400 cm.

There are few, if any, noteworthy contributions from the terrestrial vegetation components in KFN-A, although Restionaceae suggest a Sand Plain Lowland Fynbos component while the Mesembryanthemaceae and Euphorbiaceae are indicative of West Coast Strandveld. Coastal Scrub Forest elements are practically non-existent, although Ebenaceae pollen is observed in small quantities. Local veld indicators include Amaryllidaceae, *Drosera* and *Oxalis*, but reflect low levels of pollen throughout the sequence. Fabaceae increase gradually to reach maximum proportion towards the top of the zone, while more specific Lowland Fynbos indicators such as the Restionaceae reflect declining proportions higher up the sequence. For the first time at Verlorenvlei, trilete scabrate fern spores (*Pteridium*) and high levels of monolete filicales are recorded from the basal deposits of the zone. In general, the consistent presence of sedges is noted from the spectra but few other fresh water indicators are recorded. The upper

zone boundary, at 170 cm, heralds an abrupt departure in sedimentation - suggestive of an hiatus in the sedimentary record at Klaarfontein.

Zone KFN-B1. As a consequence of the first of two hypothesised sedimentary discontinuities in the sequence, sediments postdating the radiocarbon date of 3 640 BP are absent from Klaarfontein. Zone KFN-B1 extends up from 175 to 105 cm and is interpreted to represent the period during which sedimentation resumed at Klaarfontein, sometime prior to 1 900 ± 60 BP (Pta 6146). The spectra are distinguished by elevated levels of pollen concentration and a dramatic increase in the pollen from riparian taxa, especially sedges and *Typha*, with the latter achieving maximum proportion in these spectra. Chenopodiaceae decline to their lowest levels in the sequence and, interestingly, a similar trend is observed among the pollen of the larger-grained Poaceae pollen and the *Stoebe*-type Asteraceae. Among the local terrestrial indicators, *Drosera* pollen and *Pteridium* spores are seen to increase, while the local aquatic elements reflect the presence of *Myriophyllum* in the spectra. The extralocal and regional pollen signal is not particularly pronounced but there is convincing evidence for an increase in the diversity of pollen from West Coast Strandveld, Lowland Fynbos and Scrub Forest types. Lowland Fynbos pollen includes Iridaceae, Geraniaceae and Restionaceae, while Scrub Forest taxa include *Myrica*, Celastraceae and Santalaceae, among others. Towards the top of the zone, small grass palynomorphs increase in frequency.

Zone KFN-B2. A brief, albeit distinct, pollen assemblage is recognised from the sediments deposited between 105 and 75 cm. The basal age of this zone is dated to 1 900 BP and the upper boundary is extrapolated to be in the order of 1 500 BP. The zone is characterised by a sharp increase in *Juncus* pollen and a simultaneous increase in *Stoebe*-type and large grass palynomorphs. A small increase in halophytes is also observed along with a decline in *Typha* pollen. Among the terrestrial indicators, the diversity of pollen taxa is seen to decline, especially among the woody scrub elements.

Zone KFN-B3. The second hiatus at Klaarfontein appears to have occurred sometime shortly after 75 cm, *circa* 1 500 BP. It is uncertain when sedimentation resumed at the site but the limited extent of the sedimentary profile in the upper sequence (75 cm) suggests that sediment accumulation could not have commenced much before 400 - 500 BP. The spectra are analogous, in many respects, with contemporaneous assemblage zones from GDV1&2 and GDV4. Poaceae pollen decline sharply, while for the first time in the sequence, Asteraceae rise to prominence. Fynbos, including Proteaceae, Restionaceae, and Rosaceae, is well represented in this zone. Among the local hydrophil elements, Cyperaceae pollen demonstrates an increase, while halophytic types decline towards

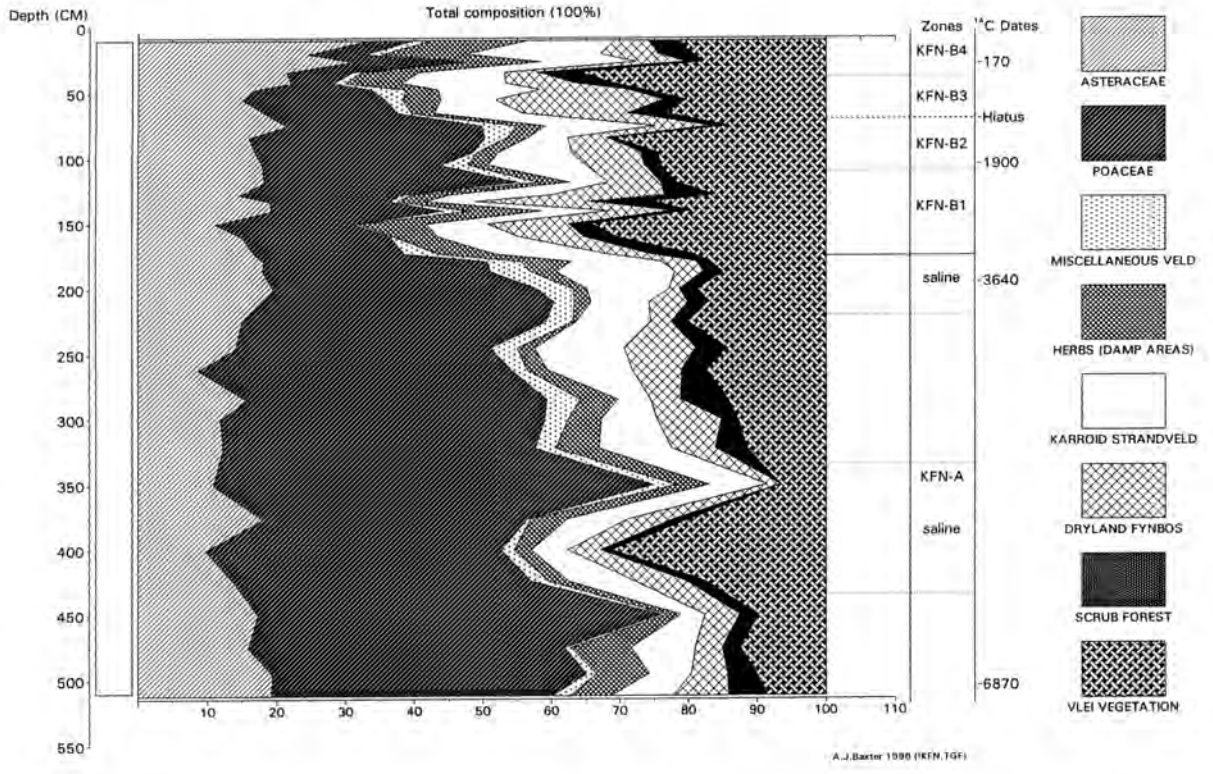
the zone boundary, ultimately disappearing from the sequence altogether. The sharp dip in Poaceae pollen at the upper zone boundary may indicate a successional change to permanent fresh water-marsh conditions as *Phragmites* gives way to sedges.

Zone KFN-B4. The uppermost zone in the KFN sequence is contemporaneous with the resolved spectra from GDV4 and represents the colonial and modern period. Echinate Asteraceae dominate the spectra while the Poaceae diminish to their lowest levels in the entire KFN sequence - having reduced their proportion by some 80 % since the mid-Holocene. The pollen of ruderal types including Scrophulariaceae and *Oxalis* increase with concomitant increases in the proportions of many Strandveld elements, especially the succulents. Fynbos, with barely any representation in the spectra, is seen to decline in favour of Strandveld and Karroid Shrubland during this time period. Celastraceae and Ebenaceae, probably *Putterlickia* and *Euclea*, are recorded from the scrub elements. The vlei vegetation once again demonstrates a fluctuation in its pollen constituents. Cyperaceae proportions are moderated by increases in *Juncus* and *Typha* pollen. A small quantity of *Pteridium* spores indicate the presence of ferns.

8.5.2.1 *Palaeoenvironmental reconstruction of KFN*

There is some ambiguity regarding the role of the artesian springs at Klaarfontein since the potential introduction of allochthonous pollen from distant sources, perhaps far removed from the influence of Verlorenvlei, is recognised as being problematic with respect to the interpretation of the vegetation history of this part of the Sandveld. Two factors are presented in defence of the reliability of the pollen record from Klaarfontein. Firstly, the Klaarfontein Springs are not considered to be associated with either the primary or secondary Sandveld aquifer, but rather reflect localised subterranean drainage from the undulating hills to the north of the site (Maclear, 1994). This implies that water-borne pollen should be representative of the extralocal and regional Sandveld vegetation and, more importantly, will be broadly contemporaneous with the sedimentary record established at Klaarfontein. The second factor concerns the location of the vibracore, KFN. The site is situated in a boggy marsh, a considerable distance from the source of the major spring and well removed from the main flow (refer to Figure 6.2). Although it is not known whether the palaeochannel of the stream flowing from the spring ever deviated, the modern context of the site suggests that the pollen in the core accumulated as a result of passive fallout of atmospheric pollen, rather than water borne pollen from the spring source.

Figure 8.23 Klaarfontein (KFN) cumulative pollen diagram



In consideration of the extralocal and regional vegetation history and palaeoenvironmental reconstruction of KFN, it is apparent from the outset that the pollen sequence reflects many of the important changes first recognised in the Grootdrift, GDV1&2 sequence. However, Klaarfontein offers additional insights as a result of a longer and more continuous sedimentary sequence, improved levels of pollen concentration and a tighter subsampling interval. Based on a combined evaluation of the sediments and their respective pollen spectra (refer to Figure 8.23), the sequence can be separated into two distinctive components, namely, a constant period of sedimentation with a coherent vegetation record from 6 800 BP to 3 450 BP and a second more dynamic period of sedimentation, with a distinct vegetation record from 3 450 BP to the present.

It is recognised that the activity of the springs during the mid-Holocene may provide important clues with respect to the local vegetation history at Klaafontein as well as the regional palaeoenvironments. However, it is has proved difficult to qualify the activity of the springs during the period of sedimentation. Contemporary observations in the mountains of the southwestern Cape suggest that the Arum lily, *Zantedeschia aethiopica* (a member of the Typhaceae family and a producer of pollen which is indistinguishable from that of *Typha*) is a classic indicator of 'spring' activity, frequently occurring in close association with *Pteridium* (personal observation). *Typha* pollen, when observed in conjunction with *Pteridium* in terrestrial sites, are thus better assigned to *Zantedeschia*.

Among the basal sediments of KFN, the presence and subsequent decline of *Pteridium* spores serve as an indication that the Klaarfontein Springs may have been active for only a short while after 6 800 BP. Sometime after 6 000 BP, *Typha*-type pollen (≈*Zantedeschia* pollen) and *Pteridium* spores are both absent from the sequence and it is speculated that the spring ceased to flow and that conditions for pollen accumulation remained tenuous until sometime after *circa* 3 450 BP.

The early mid-Holocene sequence provides little in the way of a terrestrial signal although low diversity among the taxa, especially the Lowland Fynbos and Scrub Forest elements, points to xeric conditions in the regional environment. Certainly, the predominance of Poaceae, Asteraceae and Chenopodiaceae in the sequence suggests that moisture availability (especially fresh water) was a critical factor throughout this time (eg, Vincens, 1987; Horowitz, 1992). The nearest-neighbour indices suggest that the West Coast Strandveld which presently occupies Skietkop and the slopes along the Verlorenvlei Farm embayment is the most appropriate modern analogue. The rolling Sandveld hills which surround the Klaarfontein site are thus envisaged to have supported a resilient karroid Strandveld component interspersed with restios, drought-resisting woody shrubs such as *Zygophyllum* and *Lycium*, and succulents such as *Lampranthus* and *Ruschia*. While the vegetation signal from the regional environment remains tenuous, there is convincing evidence for hydrological and palaeolimnological adjustments at the Klaarfontein site during the same period. It follows from the interpretations first made at Grootdrift that, on the basis of the apparent relationship exhibited between the large-grained pollen from grasses (eg, *Spartina* and *Sporobolus*) and the pollen from halophytes (eg, Chenopodiaceae and *Limonium*), distinct episodes of hypersalinity occurred at Klaarfontein during the mid-Holocene. Two peaks in the halophytic vegetation allude to the possible pulsing of sea water up the system and the temporary establishment of estuarine or saltmarsh conditions near to the site. The first peak occurs, abruptly, sometime between 6 200 and 5 500 BP and the second, more gradual occurrence, sometime between 4 370 and 3 450 BP. The pollen spectra from both these peaks are well correlated with the modern spectra from the Verlorenvlei mouth and Wadrifsoutpan (Figure 8.24). An interpretation of estuarine conditions in Verlorenvlei during this latter phase is entirely consistent with the palaeoenvironmental record from the Grootdrift transect, and is coincident with the mid-Holocene (4 000 BP) event, first proposed by Yates *et al.* (1986). The earlier peak in saltmarsh vegetation in the basal sediments of KFN provides the first indication of an even earlier transgressive sea-level - an event which pre-dates the predicted mid-Holocene high by some 2 000 radiocarbon years. Unfortunately there is very little alternative palaeoenvironmental evidence from Verlorenvlei against which to evaluate

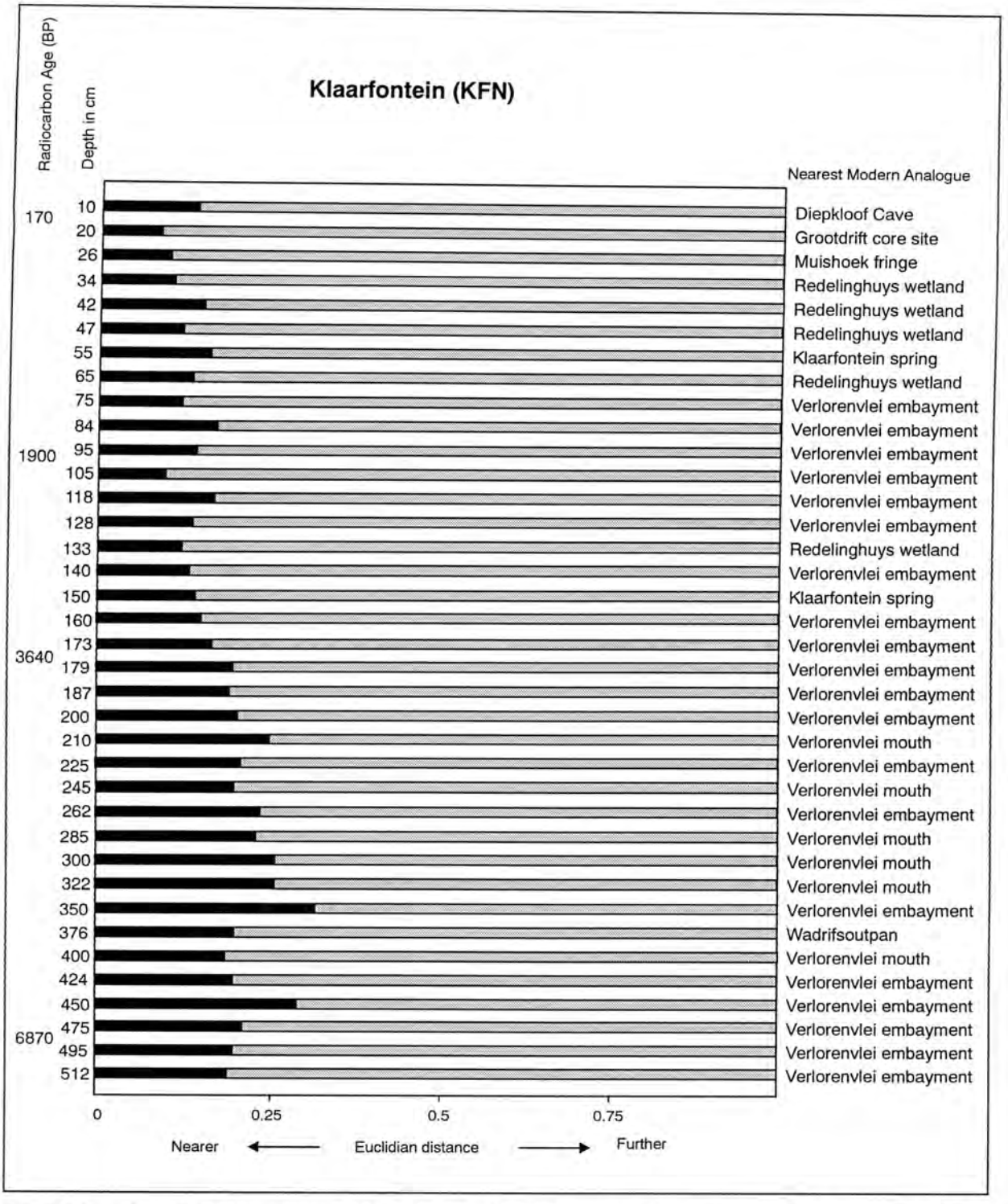


Figure 8.24 Nearest Neighbour Indices (NNIs) for the KFN pollen spectra. (Refer to Table 6.4 for a description of the analogue sites).

the interpretation of an early mid-Holocene marine insurgence. However, the supposition is consistent with the 2.4 - 2.8 m amsl transgressive event recorded from Knysna Lagoon and dated to 6 200 BP (Marker and Miller, 1993; 1995) and the marine intrusion which is credited with the formation of Langebaan Lagoon, sometime around 6 500 BP (Flemming, 1977a). It is not clear from the pollen data whether or not sea-levels

regressed from Klaarfontein following this early phase, *circa* 6 000 BP; however, the persistence of halophytes at Klaarfontein throughout the lower sequence suggests that, until 3 450 BP, the influence of saline water was never very distant.

If sea-level encroachment can be used to explain alterations among the halophil and hydrophil vegetation at Klaarfontein, then a rapid regressive event might be used to explain the absence of sediments from the site after 3 450 BP. Such a scenario finds support among the proxy archaeological evidence of Jerardino (1993), who argues that a rapid drop in sea-level occurred after 4 000 BP. In conjunction with the geoarchaeological evidence of Miller *et al.* (1993), Jerardino (1995) has inferred a sea-level regression at Verlorenvlei, to a minimum of –1 m amsl, sometime between 3 500 and 2 800 BP. It thus seems probable that sedimentation only resumed at Klaarfontein sometime after 2 500 BP - by which time the pollen-rich spectra are clearly indicative of increased moisture availability in the regional environment. Certainly, by 1 900 BP, diverse communities of Lowland Sand Plain Fynbos and Restioid Strandveld had come to be established among the rolling hills to the north of Klaarfontein, while Afromontane Scrub Forest elements including *Olea, Podocarpus* and *Colpoon* are seen to have occupied the sheltered ravines around the sandstone koppies. A proliferation of herbs, ruderals and Asteraceous shrubs, typical of damp areas, suggests that the Klaarfontein Springs were active once again, while the presence of aquatics, such as *Myriophyllum* and *Aponogeton,* provides convincing evidence that fresh water conditions had come to replace the saline conditions in the upper reaches of Verlorenvlei. Reed vegetation appears to have been prolific at the site, and the predominance of saline-intolerant varieties, including *Cyperus* and *Typha* suggests that the influence of the sea was, at this time, far removed from the site.

Cooler and moister conditions prevailed until shortly after 1 900 BP, following which the KFN spectra once again reflect the presence of saline, possibly more xeric, conditions in proximity to Klaarfontein. *Typha* and *Cyperus* are seen to give way to a succession of *Juncus* and probably *Phragmites* (the latter indicated by the predominance of smaller, uniform grass palynomorphs) and a reappearance of Chenopodiaceae and Mesembryanthemaceae - an intimation, possibly, that sea-levels were once again on the increase and that the saline interface was advancing up the Verlorenvlei. From the stratigraphy and chronology it is clear that a sediment incongruity took place at Klaarfontein some time around 1 500 BP, at which point the pollen record ceases for the second time in the sequence. Since evidence for isostatic equilibration is unclear for this period, it is uncertain whether rejuvenation of the Verlorenvlei River can be used to account for the missing sediments at Klaarfontein. An alternative hypothesis is that a

brief but intense period of regional aridity may have stemmed the spring activity at Klaarfontein and suspended sedimentation at the site. There is some measure of support from the observed vegetation pattern immediately prior to the hiatus, since the pollen signature is consistent with the absence of fresh water at the site, indicating enhanced aridity in the terrestrial environment.

The uppermost spectra of KFN are comparatively modern and record the vegetation history from the immediate pre-colonial period through to the modern day. There is much commonality between these spectra and those from GDV1&2 and GDV4. The regional vegetation appears at first to be broadly similar to that of the late mid-Holocene, with diverse representation from the fynbos and Strandveld communities. Towards the surface the spectra are considerably less diverse, with an increase in succulents and disturbance indicators at the expense of fynbos elements. Human impact appears to be the overriding factor in the determination of vegetation ecology during the last 170 years - confirmed in part by the exponential increase in asteraceous taxa and the striking Poaceae decline. Cyperaceae, *Juncus* and *Typha* reaffirm the successional status of the contemporary upper Verlorenvlei to a marsh situation.

Fortuitously, the extended late mid-Holocene sedimentation record from Klaarfontein has provided additional insights regarding the progressive Poaceae decline - a marked trend which has endured since 1 900 BP. Smith (1987) has demonstrated that Khoi Khoi pastoralists were on the Vredenburg Peninsula by 1 860 BP, while the records of early travelers confirm that sheep and cattle were grazing in the Verlorenvlei valley prior to the arrival of European settlers (Sinclair, 1980). During this pre-colonial phase there appears to have been a consistent decline of pollen from grasses, both at Klaarfontein and Grootdrift. Concurrently, the pollen spectra show an increase in 'unpalatable' ecological equivalents of grass, such as the restioid, *Willdenowia*, and various echinate Asteraceae. This prompts the question as to the impact of indigenous pastoralists in the region. Historical records (eg, Skead, 1980) bear testimony to the practice of firing reed beds to promote new growth - a practice which continues annually among the *Phragmites* and *Typha* reed beds to this day. An abundance of microscopic charcoal fragments have been observed from among the pollen of KFN samples derived at 75, 84 and 95 cm respectively. It may be a coincidence that these charcoal-bearing samples happen to correspond with declining grass values following the radiocarbon date of 1 900 BP, but it is tempting, nonetheless, to assign the postulated changes in vegetation ecology to a new economic and political dispensation in the Verlorenvlei region.

In summary, the evaluation of autochthonous fossil pollen from Klaarfontein reveals new insights with respect to the complex palaeolimnology, palaeohydrology and palaeogeomorphology of the Verlorenvlei system during the Holocene. Two possible high sea-level events are evident in the pollen from saltmarsh vegetation. A thorough evaluation of the regional terrestrial pollen signal reveals strong evidence for regional aridity during the early mid-Holocene followed by an amelioration to moister conditions during the late-mid-Holocene. Possible evidence linking Khoi Khoi pastoralism to alterations in the vegetation ecology, especially grasses, is noted for the last 2 000 years.

8.6 Muisbosskerm se Groot Sloot

The incidental discovery of a wedge of sandy organic 'peat' towards the base of a 2 m trench on the farm Muisbosskerm, prompted much speculation about former environmental conditions along the coastal margin. The peaty deposit (a fibrous *Typha* matrix) was considered to be anomalous in view of the fact that the site is situated behind the primary dune cordon (± 5 m amsl) and is presently blanketed by 1.5 m of littoral sands and is surrounded by spinescent vegetation with a strong karroid affinity. It was hypothesised that conditions for peat formation at the site would have required a pronounced shift in the local hydrology with possible implications for enhanced moisture availability in the Sandveld.

8.6.1 Stratigraphy and chronology

The Muisbosskerm trench demonstrates impressive proportions, measuring 2 m deep, 4 m wide and many hundreds of metres in linear extent. The abandoned exposure, once intended for an agricultural venture, traverses northeastwards from the coast road, across a recessed depression and inland towards the slightly elevated coastal forelands. A suitable section of exposed trench, some 100 m from the coastal road, was cleaned and prepared for description and sampling. The section drawing (Figure 8.25) reveals that a 60 cm wedge of dense, fibrous *Typha*, interspersed with sand and clay, occurs at a depth of around 175 - 117 cm. Following an abrupt facies change at 117 cm, a consistent, dark grey, horizontally stratified, organic sand layer extends up to 65 cm. A sharp horizontal boundary at this level, followed by a 20 cm grey-brown sandy horizon, marks what is believed to be a deep ploughing interface within the stratigraphy. Ploughing interfaces of similar proportion and composition are observed at 45 and 25 cm respectively. A single radiocarbon sample, selected at 147 cm, dates the middle of the

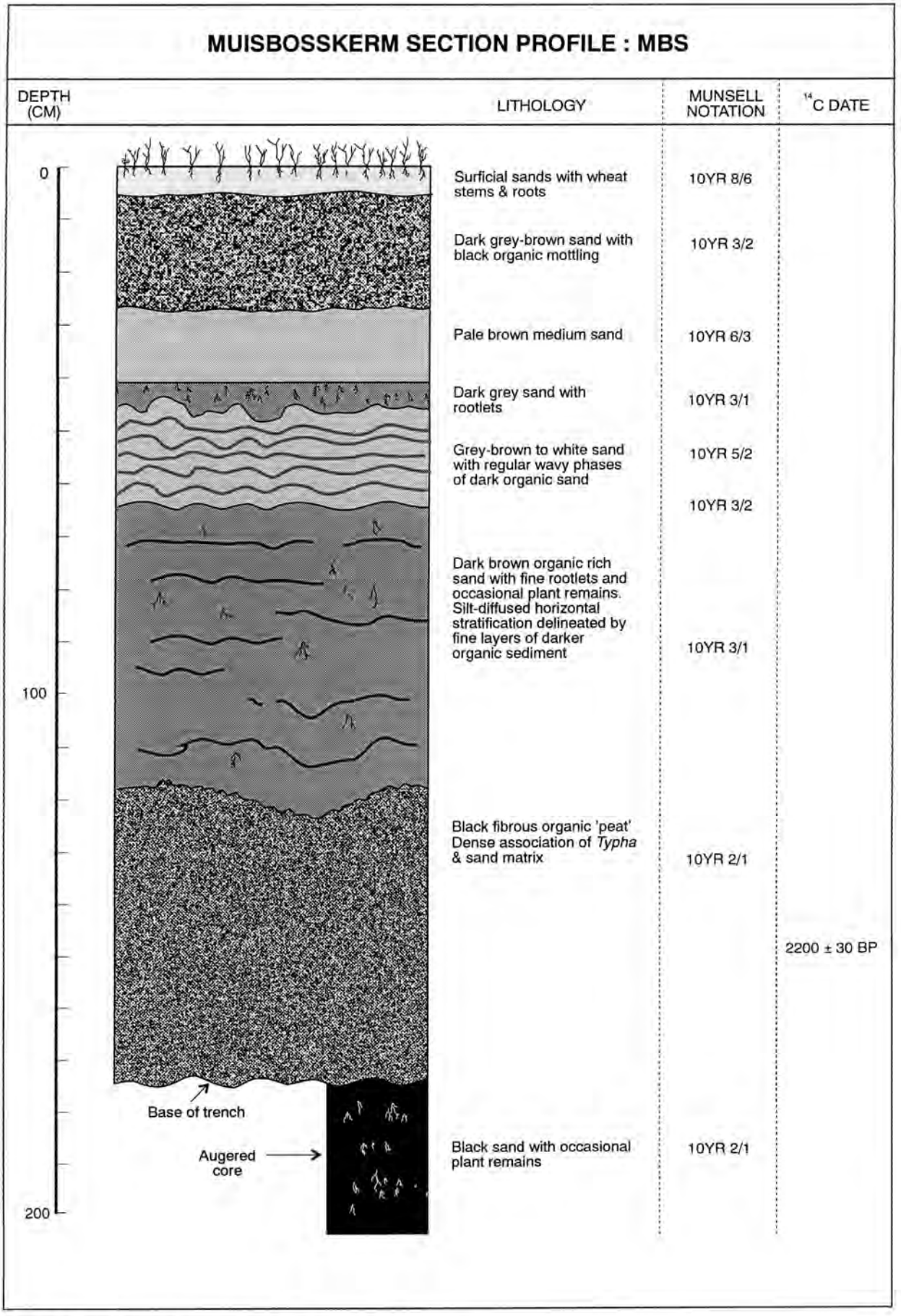


Figure 8.25 Muisbosskerm se Groot Sloot section profile : MBS.

peaty layer to 2 200 ± 30 BP (Pta 6351, calibrated to 185 BC, with a 1 σ range of 198 - 165 BC). From a spatial perspective, it is noted that the elevation of the trench rises gradually to the northeast, and as it does so, the conspicuous peaty wedge becomes less and less distinct in the sequence. Towards the terminal end of the trench, near the farmhouse, exploratory digging through the bottom of the trench, confirms that, by this point, the peaty wedge has pinched out.

8.6.2 The Muisbosskerm (MBS) pollen diagrams

Bulk samples, totaling 26, were collected from the open stratigraphic sequence, while an additional 8 samples were collected from an augured core derived from beneath the saturated basal sediments of the exposed trench. Loss-on-ignition (Figure 8.26) reveals that organic matter is comparatively high throughout the lower half of the sequence, with average values around 15 mol mg^{-1}. Above the distinctive peat horizon, from 115 cm to the surface, values decline to less than 3 mol mg^{-1}.

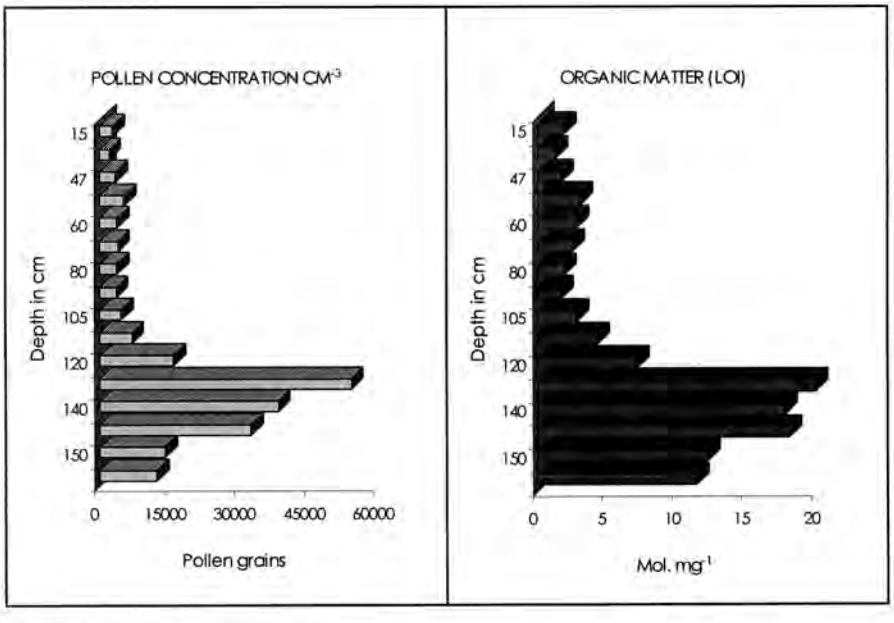


Figure 8.26 Pollen concentration and organic matter (LOI) values for MBS.

On the basis of the stratigraphy and organic matter values, 20 samples were selected for pollen analysis. In light of the large proportions of clastic material and the apparent lack of organic material among the upper strata, subsamples in the order of 30 g each were selected for pollen preparation. Coarse sieving and mineral separation proved to

be the most effective method of eliminating the substantial clastic component. Pollen concentration levels (Figure 8.26) reflect the overall trend in organic matter content, with basal strata averaging around 25 × 10^3 grains cm^{-3}, while concentrations in the sandy upper levels average only 3 - 4 × 10^3 grains cm^{-3}. With only a single date from the 1.8 m Muisbosskerm sequence, pollen accumulation rates have not been calculated. There is also some uncertainty regarding the sedimentation rate following the organic phase around 2 200 BP.

With respect to the pollen counts, large subsamples ensured reasonable quantities of pollen with some slides yielding in excess of 700 palynomorphs $slide^{-1}$. The pollen sum includes all the taxa, less the huge quantity of filicales which were recorded and graphed independently. The comprehensive and summary (ECODE) pollen diagrams for Muisbosskerm are presented in Figures 8.27 and 8.28 respectively. Low representation among Strandveld and Lowland Fynbos elements has been compensated for, in the summary pollen diagram, by exaggerated scales. Statistical zonation of the MBS pollen data recognizes the dichotomy in the pollen sequence, and two principal assemblage zones are indicated in the diagrams. For discussion purposes, the upper pollen assemblage zone has been further delimited into two subzones.

Zone MBS-A. This lower zone incorporates the spectra from one of the augered samples, at 188 cm, and the spectra from the fibrous peat layer, which extends from 175 cm until the facies change at 117 cm. A malfunction during the final stage of laboratory preparation resulted in the loss of five pollen samples from this zone. Their absence is reflected in the MBS pollen diagrams by the dearth of pollen counts between 188 and 155 cm. It is acknowledged that the graphical inference, attenuated between these points, is therefore entirely hypothetical. However, the spoilt samples were all derived from within the dense organic *Typha* matrix and there is no reason to expect any marked variability among their pollen spectra. The zone is dated to 2 200 BP and is characterised by a predominance of Poaceae pollen and the pollen from riparian vegetation including: Cyperaceae, *Juncus* and *Typha*. Small grass palynomorphs among the Poaceae pollen are suggestive of *Phragmites*. There is a strong representation among the pollen of West Coast Strandveld taxa such Aizoaceae, Anacardiaceae and *Zygophyllum*. The fynbos is characterised by large proportions of Restionaceae, and minor contributions from the Lamiaceae and Rosaceae families. Coastal Scrub Forest is well represented by the pollen of Ebenaceae, Celastraceae and, to a lesser extent, *Myrica* and Santalaceae. Chenopodiaceae are a consistent feature throughout the zone but never achieve more than 5 % of the spectra.

Figure 8.27 Muisbosskerm (MBS) comprehensive pollen diagram

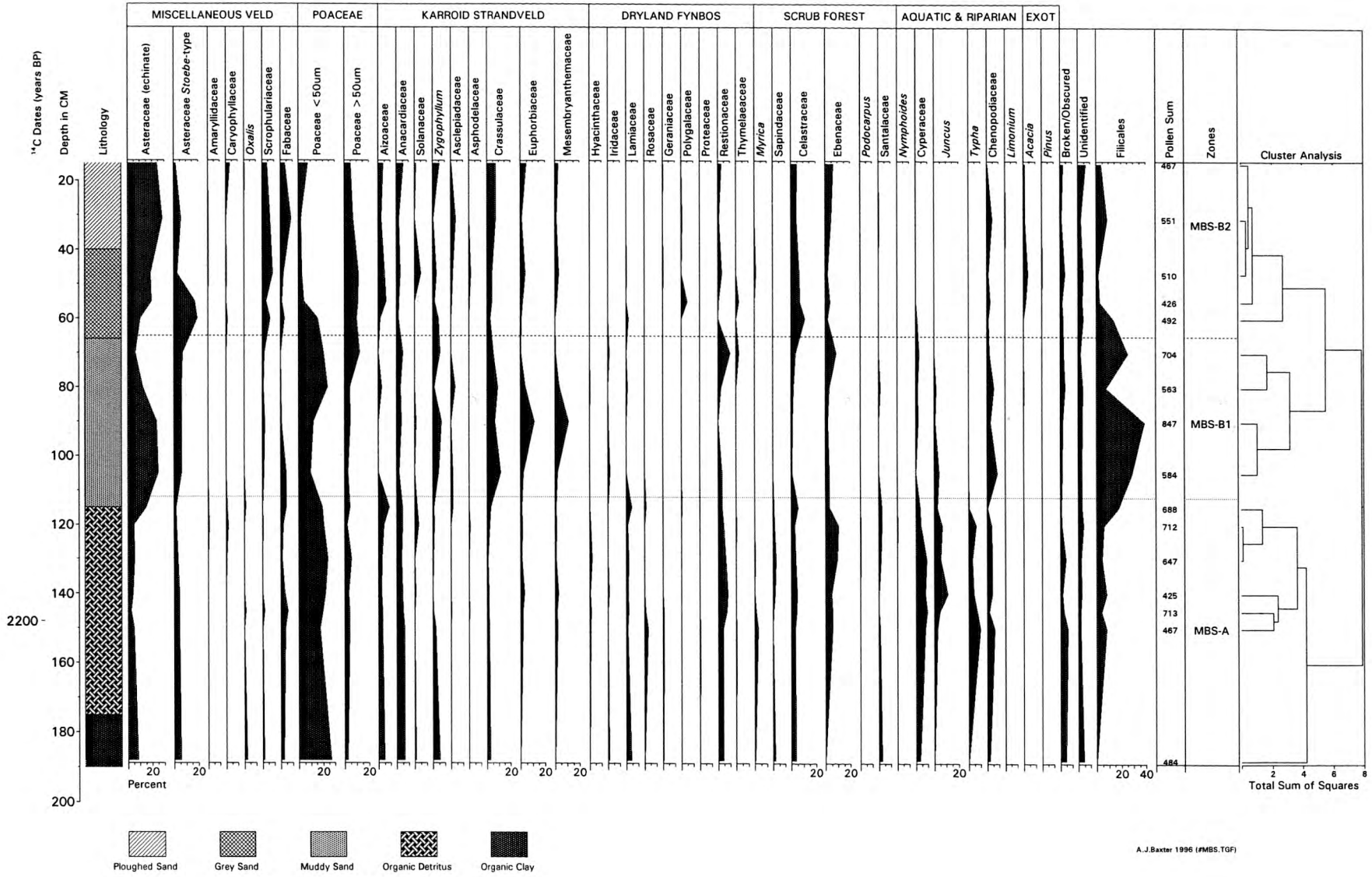
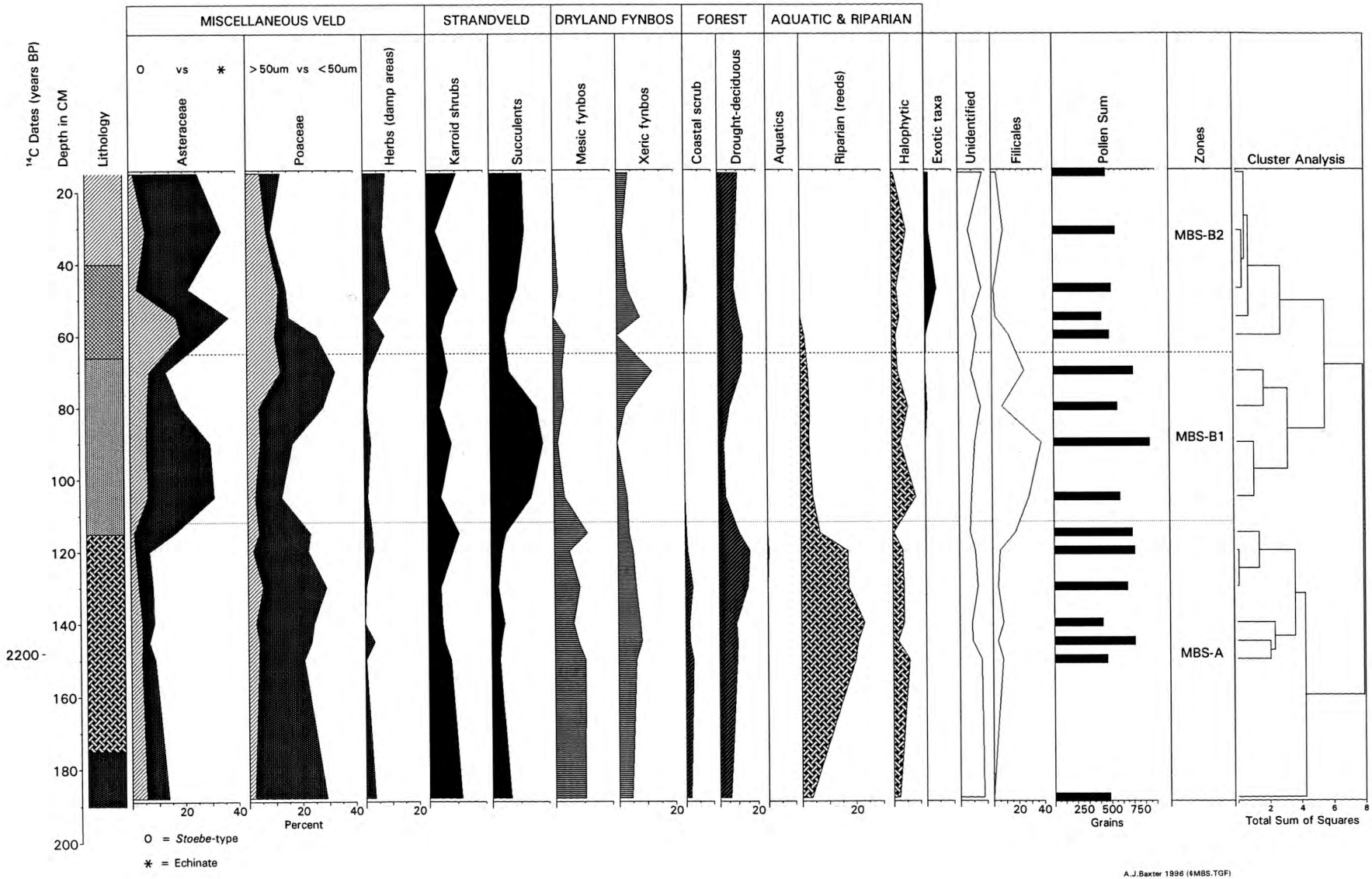


Figure 8.28 Muisbosskerm (MBS) summary (ECODE) pollen diagram



Zone MBS-B1. Following the peaty *Typha* layer, this zone is characterised by a decline in pollen concentration and a massive increase in filicales. From 117 to 65 cm, the dark organic sand with laminations and rootlets advertises a significant departure in sedimentation at the site, an observation supported by a pronounced change in the pollen of terrestrial components. Asteraceae reach their highest proportion in the sequence, while a concomitant decline in grass pollen is apparent. Karroid Shrubland is the predominant form with abundant pollen from succulent types, including; Asclepiadaceae, Crassulaceae, Euphorbiaceae and Mesembryanthemaceae. Woody elements are reflected in the pollen of Zygophyllum. There is poor representation from the fynbos and coastal Scrub Forest elements and even the ubiquitous restioid types are rare. *Typha* is no longer recorded in the sequence and only small contributions (< 5 %) are made from the sedges and *Juncus* reeds. Chenopodiaceae are well represented in this level. Towards the zone boundary at 65 cm, the ratio of Poaceae to Asteraceae pollen fluctuates. A synchronous peak in Restionaceae and Celastraceae pollen is also apparent at this time.

Zone MBS-B2. The uppermost spectra, from 65 cm to the surface, are problematic. Unusual stratigraphic features in the top 50 cm of deposit are interpreted as deep ploughing horizons. This assertion is confirmed by the presence of exotic pollen from *Acacia* and *Pinus* spp., towards the base of the pollen assemblage zone. Despite the implication of mixed, inverted and chronologically reversed sediments, a consistent feature, throughout this zone, is the reduced levels of Poaceae pollen, the abundant contributions from Asteraceous types and the prevalence of succulents and drought-deciduous woody shrubs. No pollen from riparian elements are recorded.

8.6.2.1 *Palaeoenvironmental reconstruction of MBS*

The discovery and subsequent investigation of the peat deposits at Muisbosskerm is especially important insofar as the sediments contain palynomorphs which date exactly to the hiatus period observed in the sedimentation record at Verlorenvlei. However, attempts to interpret the vegetation history of the extralocal and regional Sandveld environments have, once again, been compounded by local fluctuations in hydrology and the preponderance of localised pollen producers. Nonetheless, the fluctuating palaeohydrological status of the Muisbosskerm site may, in itself, be an important clue as to the nature of the regional palaeoenvironments, since this modern dryland site is devoid of any allochthonous aquatic input, other than marine intrusions or rainfall and seepage.

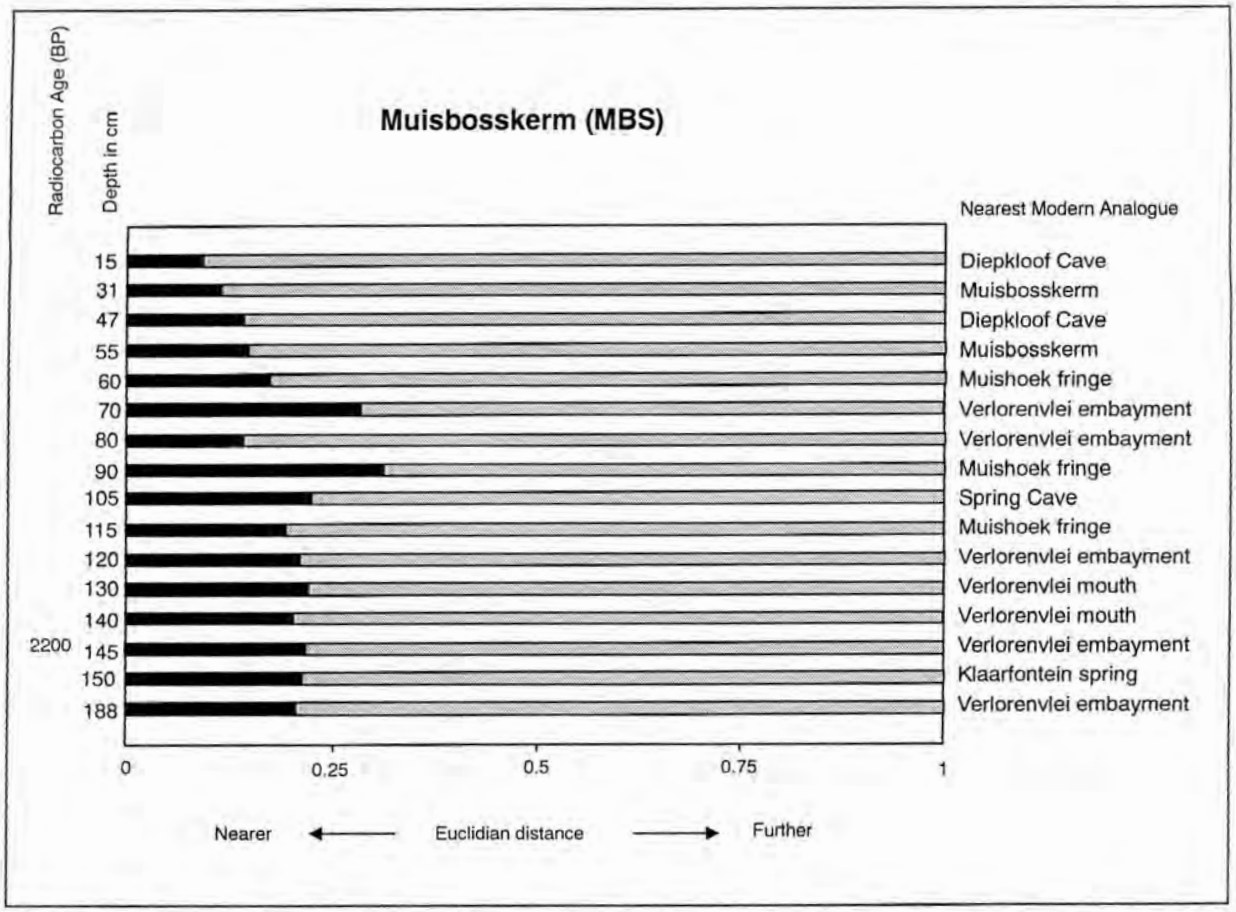
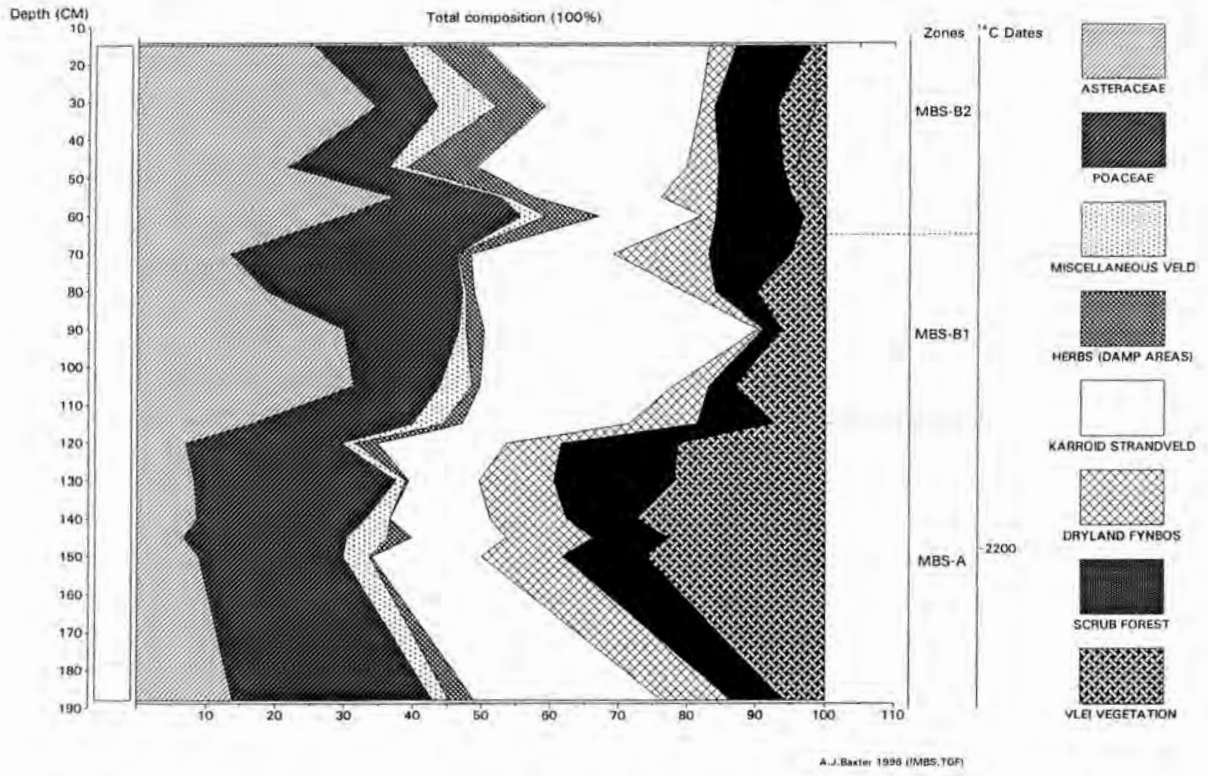


Figure 8.29 Nearest Neighbour Indices (NNIs) for the MBS pollen spectra. (Refer to Table 6.4 for a description of the analogue sites).

From the stratigraphy and pollen record it is apparent that fresh water was at a premium in the dune slack at Muisbosskerm sometime between 2 500 and 2 000 BP. The fossil spectra for this period are well correlated with the riparian vegetation communities which presently occur around the springs at Klaarfontein and along the Verlorenvlei embayment (Figure 8.29). Unfortunately, there is no certainty regarding the role of *Phragmites* at Muisbosskerm, but the large proportion of *Typha* suggests that the site was permanently saturated and that salinity levels were low (*Typha* are not especially saline tolerant). The presence of *Nymphoides*, although a very minor constituent, provides some measure of support for this interpretation, as does the depleted $\delta^{13}C$ measurement of -26.3 ‰, supplied with the radiocarbon date. The duration of this fresh water phase at Muisbosskerm remains enigmatic, although the spectra suggest that it was a progressive event which waxed and waned around the date of 2 200 BP. Two plausible explanations for the perceived increase in moisture at the site during the late mid-Holocene are proposed. The first relates to a possible transgressive adjustment of relative sea-level, and the other to increased precipitation along the West Coast. A transgressive sea-level, perhaps in the order of 1 - 2 m amsl, would have contributed to an appreciable elevation of the water table in the dune slack at Muisbosskerm. Provided that the existing foreshore dune barrier remained unbreached, an increase in sea-level

Figure 8.30 Muisbosskerm (MBS) cumulative pollen diagram



would ensure that runoff from springs and subterranean seepage from the Sandveld aquifer would accumulate in the depression and remain perched above the newly adjusted saline interface. Although such an interpretation is compatible with the present day geohydrological characteristics of the West Coast (Maclear, 1994), there is no supporting evidence for a relative increase in sea-level at this time (Miller *et al.*, 1993; Jerardino, 1995). In fact, the only available evidence from southern Africa points towards a minor negative oscillation sometime between 2 000 and 3 000 BP (Illenberger and Verhagen, 1990).

The second hypothesis put forward to account for the perceived increase in moisture at Muisbosskerm during the late mid-Holocene, draws on the regional terrestrial vegetation signal. Reference to the cumulative pollen diagram (Figure 8.30) reveals that the rise to prominence of local riparian vegetation at the site, *circa* 2 200 BP, is complimented by the appearance of conspicuous coastal Scrub Forest elements in the extralocal and regional environment. Modern distributions of Celastraceae and Ebenaceae in the Sandveld, commonly include taxa such as *Maytenus, Putterlickia, Diospyros* and *Euclea*. The occurrence of such elements, near Muisbosskerm, in conjunction with woody Strandveld elements such as; *Rhus, Myrica, Salvia* and *Colpoon*, are an indication that conditions were comparatively moister than today. The overall picture is one of a woody Strandveld scrub, interspersed with the restioid, *Willdenowia*, and herbaceous elements such as *Hebenstreitia, Grielum* and *Lessertia*. Unfortunately,

the poor taxonomic resolution attached to the fossil pollen record is such that the finer details of this vegetation history reconstruction, remain inconclusive. However, the gross evidence, when viewed together, presents a compelling case in favour of moister regional climates around 2 200 BP. Such a scenario is concordant with palynological evidence from elsewhere in the southwestern Cape (refer to Chapter 2), with proxy archaeological evidence at Verlorenvlei (Jerardino, 1995) and with microfaunal evidence in Namaqualand (Avery, 1992). Thus, the development of a wetland at Muisbosskerm is envisaged to have been a product of elevated runoff and enhanced artesian discharge from the Sandveld aquifer, rather than sea-level deviation. Fresh water is expected to have dammed up behind the seaward dune cordon forming an extensive endoreic, back-barrier fresh water lagoon.

In the upper assemblage zone, probably sometime after 2 000 BP, there is evidence for a progressive alteration in both the local and extralocal vegetation at Muisbosskerm. An abrupt departure in sedimentation at around 117 cm is commensurate with declining pollen concentration and organic matter content (Figure 8.26) - features which are believed to be indicatory of low levels of primary productivity in the coastal landscape. Sediments do not appear to have accumulated especially rapidly at Muisbosskerm and a sudden influx of littoral sand under an enhanced aeolian regime can therefore be discounted as a reason for the observed change in status of the site. Instead, the absence of macrophytic remains and pollen from *Typha*, together with the palaeosol-like characteristics of the sediments, suggest that the site may have dried up due to a shift in climate to more xeric conditions. An alternative possibility is that a breach of the dune barrier may have occurred - a factor which would account for significant geomorphological change at the site. However, this latter scenario does not accord with the fundamental changes witnessed in the regional pollen spectra. Rather, the bulk of the evidence points to drier conditions in the Sandveld, with the coastal areas supporting vegetation comprising succulents and woody elements with a strong karroid association. There are some parallels between the late mid-Holocene vegetation history reconstruction from Muisbosskerm and those from Klaarfontein and Grootdrift - although succulence is recognised as being most pronounced at Muisbosskerm during this period. It is uncertain whether the introduction of domestic stock into the region could have produced the observed vegetation patterns. Small quantities of charcoal in the samples suggests that fire was a factor in the local environment. The massive influx of monolete spores in the spectra is difficult to qualify, but may be related to physical changes in the status of the local wetland.

The final assemblage zone defies meaningful interpretation since the spectra are so obviously shuffled. Taken as a whole, the spectra hint at some degree of climatic amelioration with increases in the frequency of Scrub Forest elements and woody Strandveld taxa. For the most part, however, the pervasive increase among the Asteraceae is seen to reflect agricultural clearance and the insurgence of asteraceous annuals (personal observation), while the presence of *Acacia* pollen marks the introduction of alien invasive taxa into the fragile coastal environment. It is interesting to note that while the character of the modern Muisbosskerm site is entirely terrestrial, there exists, within 3 km of the present site, isolated wetland environments in the coastal dune slack. Some of these *Typha*-dominated aquatic environments appear as small oases around perennial springs such as those on the farm Grootvlei, others have been deliberately dammed for pumping and domestic exploitation. Oral tradition has it that towards the earlier part of this century, these isolated aquatic features were once integrated into an extensive 'lagoon', capable of supporting small boats (R Yates, personal communication). Apparently, visiting hunters engaged in regular duck shooting in this area. There is good reason - implicit in the name Grootvlei (large vlei) - to assume that the back-barrier lagoon was more extensive during historical times - but not to the extent that it reached Muisbosskerm. If the site was indeed incorporated into such a lagoon during the late mid-Holocene, then the water feature is envisaged to have been fairly substantial, stretching continuously for many kilometers along the dune slack and providing a wealth of vital resources to hunter-gatherer communities in residence at the adjoining Steenbokfontein Cave (eg, Jerardino and Yates, 1996).

8.7 Spring Cave

The Spatial Archaeological Research Unit (SARU) at the University of Cape Town has been researching the human cultural record from Spring Cave for some years. In 1989 four sediment samples were assessed by J Sugden in an attempt to establish the viability of a detailed fossil pollen study at the site. The investigation revealed poor levels of pollen concentration and a large proportion of badly corroded palynomorphs, especially in layers with a high charcoal presence. Owing to problems of representivity, the original project was temporarily put aside. At the request of SARU, the site was visited by the author in April 1993 and 11 bulk pollen samples were selected from a dated archaeological exposure for detailed pollen analysis. The results are presented below.

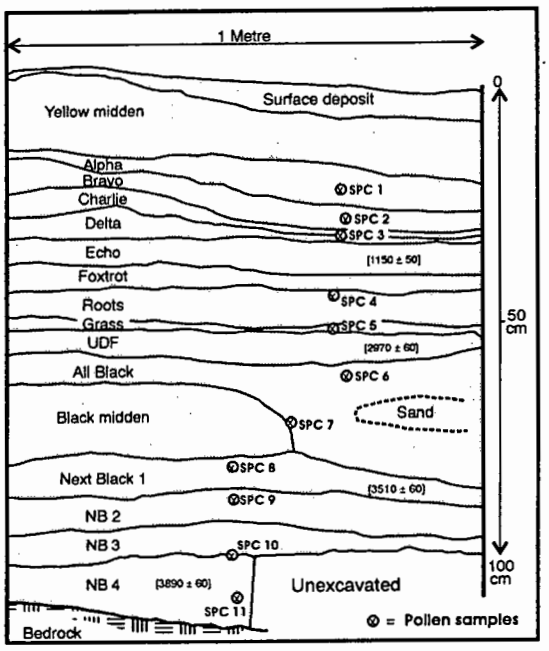


Figure 8.31 Spring Cave I9/H9 section drawing.

8.7.1 Stratigraphy and chronology

The section drawing of *sondage* I9/H9 is detailed in Figure 8.31. The 1.3 m deep profile reveals a complex stratigraphy above the basal date of 3 890 ± 60 BP (Pta 6226), secured from the Next Black 4 layer, immediately above bedrock. Additional radiocarbon dates have been returned for samples derived from Next Black 1 (± 80 cm), 3 510 ± 60 BP (Pta 4027), UDF (± 60 cm), 2 970 ± 60 BP (Pta 4033), and Echo (± 40 cm), 1150 ± 50 BP (Pta 4035). A range of deposits are associated with Spring Cave, viz: chemical precipitates such as gypsum, breccias resulting from roof spalls, aeolian sediment derived from wind-blown material and organic sediments arising out of human or animal activity. Given the myriad of potential sources of deposit, the calculation of sedimentation rates, as an index of palaeoenvironmental conditions, has little meaning in the context of Spring Cave. For example, sediments from the Next Black layers contain charcoalised remains, large shell fragments, fossilised plant debris, bones and other cultural remains which have obviously contributed to the natural rate of sediment accumulation. Nevertheless, casual reference to the distribution of the radiocarbon ages attests to a pronounced reduction in the rate of sediment accumulation sometime between 2 970 and 1 150 BP. Miller *et al.* (1993) have recognised, on the basis of sterile sediments devoid of cultural debris, that Spring Cave was not occupied from 3 000 to 1 500 BP. This implies that the sedimentary discontinuity, identified around this time period, is probably the result of non-occupation. Following the date of 1 150 BP, the uppermost surface layers have also assembled slowly and do not appear to bear evidence that supports regular occupation of the cave shelter during the last millennium (R Yates, personal communication).

Despite the sedimentary discrepancies between naturally accumulating and culturally 'accelerated' horizons, the Spring Cave sequence coincides, almost exactly, with the sedimentary hiatus reflected at Grootdrift and Klaarfontein - in other words, it fits in the chronological gap.

8.7.2 The Spring Cave (SPC) pollen diagrams

Eleven bulk pollen samples, in the order of 30 - 50 g each, were processed from the Spring Cave sequence. A high proportion of marine shell ($CaCO_3$), sintered organic matter (eg, bone fragments) and charcoal obligated the use of additional chemical procedures for pollen concentration. Prolonged soaking in HCl, sieving (down to 180 μm) and flotation techniques, were applied in order to dissolve the $CaCO_3$, separate the macroscopic remains and float off excess charcoal, respectively. Standard procedures of zinc chloride separation and acetolysis were employed in the final stages of chemical purification. Despite repeated experimentation, it proved impossible to eliminate the fine (5 - 50 μm) charcoal remains without excessive damage to the pollen grains since they proved resistant to almost every known chemical treatment. Even heavy liquid techniques were compromised by the fact that microscopic charcoal fragments behave in a similar fashion to pollen, and generally defy separation. Slide mounts were prepared using silicon oil, rather than glycerol, since the greater fluidity of the oil allowed for easier manipulation of the pollen grains on charcoal contaminated slides.

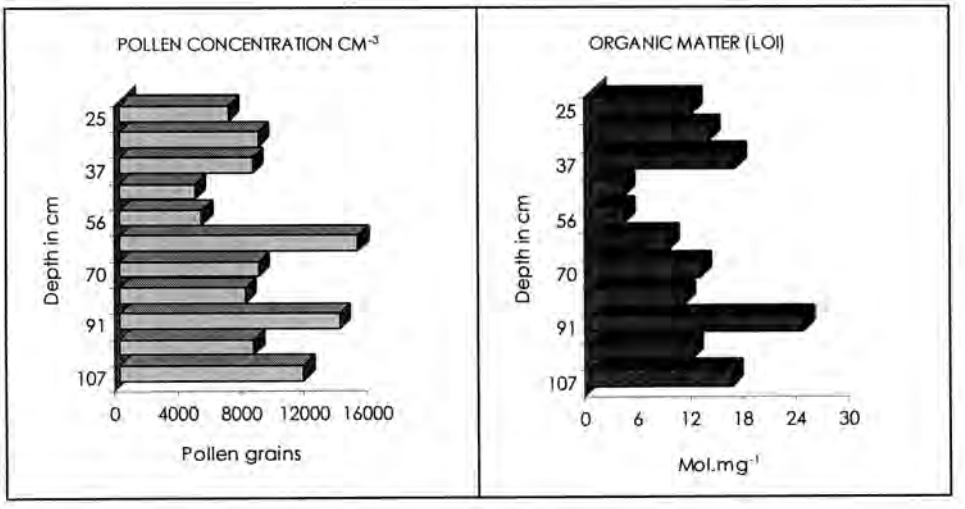


Figure 8.32 Pollen concentration and organic matter (LOI) values for SPC.

Poor pollen concentration was a factor throughout the sequence (Figure 8.32), although the large bulk samples produced reasonable pollen counts from all levels.

Pollen accumulation rates have not been calculated since the rate of sediment accumulation is subject to interpretation. Organic matter content is, similarly, not a reliable palaeoenvironmental indicator, particularly since organic bedding material, fire wood, edible plant matter and shellfish are understood to have been introduced to the site during periods of occupation (R Yates, personal communication). However, the LOI results (Figure 8.32) are useful in drawing attention to the occupational hiatus between 60 and 40 cm. Measures of organic matter reach almost 30 mol mg^{-1} (or 30 % by mass of the sample) in the cultural layers of Next Black 4, yet, decline to less than 4 mol mg^{-1} in the culturally sterile, visually depauperate, layers of Foxtrot and Roots.

The pollen spectra from Spring Cave are presented in the comprehensive and summary pollen diagrams, Figures 8.33 and 8.34, respectively. In keeping with the pollen diagrams from Grootdrift, Klaarfontein and Muisbosskerm, the Spring Cave pollen diagrams are plotted as continuous curves. Given an average sediment accumulation rate of 0.3 mm $year^{1}$ and a wide sampling interval (± 10 cm), it is acknowledged that there are substantial *time* gaps in the sequence for which the continuous curve graphs have plotted hypothetical trends. Nonetheless, this method of presentation is preferred for Spring Cave, since the resolved histogram method does not facilitate easy visual interpretation. Statistical zonation has recognised the hiatus among the pollen spectra, but is suggestive of a lack of continuity among the older spectra which precede the hiatus. The large proportion of Chenopodiaceae, as well as the other riparian taxa, have not been included in the pollen sum used to generate the graphs of the terrestrial elements.

Zone SPC-A. From the base of the sequence, at 3 890 BP, this zone extends up to a depth of 68 cm and an inferred age of around 3 200 BP. Prominent within the spectra are the Asteraceae and Poaceae, with combined proportions reaching almost 50 % of the total counts. Among the other veld elements, both Scrophulariaceae and Fabaceae are well represented, reaching their respective maximum proportions by the zone boundary. Strandveld components are dominated by the Anacardiaceae and especially *Zygophyllum*, while the Euphorbiaceae and Mesembryanthemaceae both achieve more than 5 % of the spectra. With the exception of Restionaceae, fynbos pollen does not occur in great abundance, although it does appear to be diverse - as demonstrated by the minor proportions of Lamiaceae, Rhamnaceae, Rosaceae, Proteaceae and Thymelaeaceae, all of which occur concurrently in this zone. Scrub Forest taxa are dominated by Ebenaceae, although *Podocarpus* are also recorded towards the top of the spectra. *Cyperus* pollen is present in small proportions, as is pollen from the Chenpodiaceae. The largest proportion of unidentified pollen (10 - 15 %) is also attributed to this zone.

Figure 8.33 Spring Cave (SPC) comprehensive pollen diagram

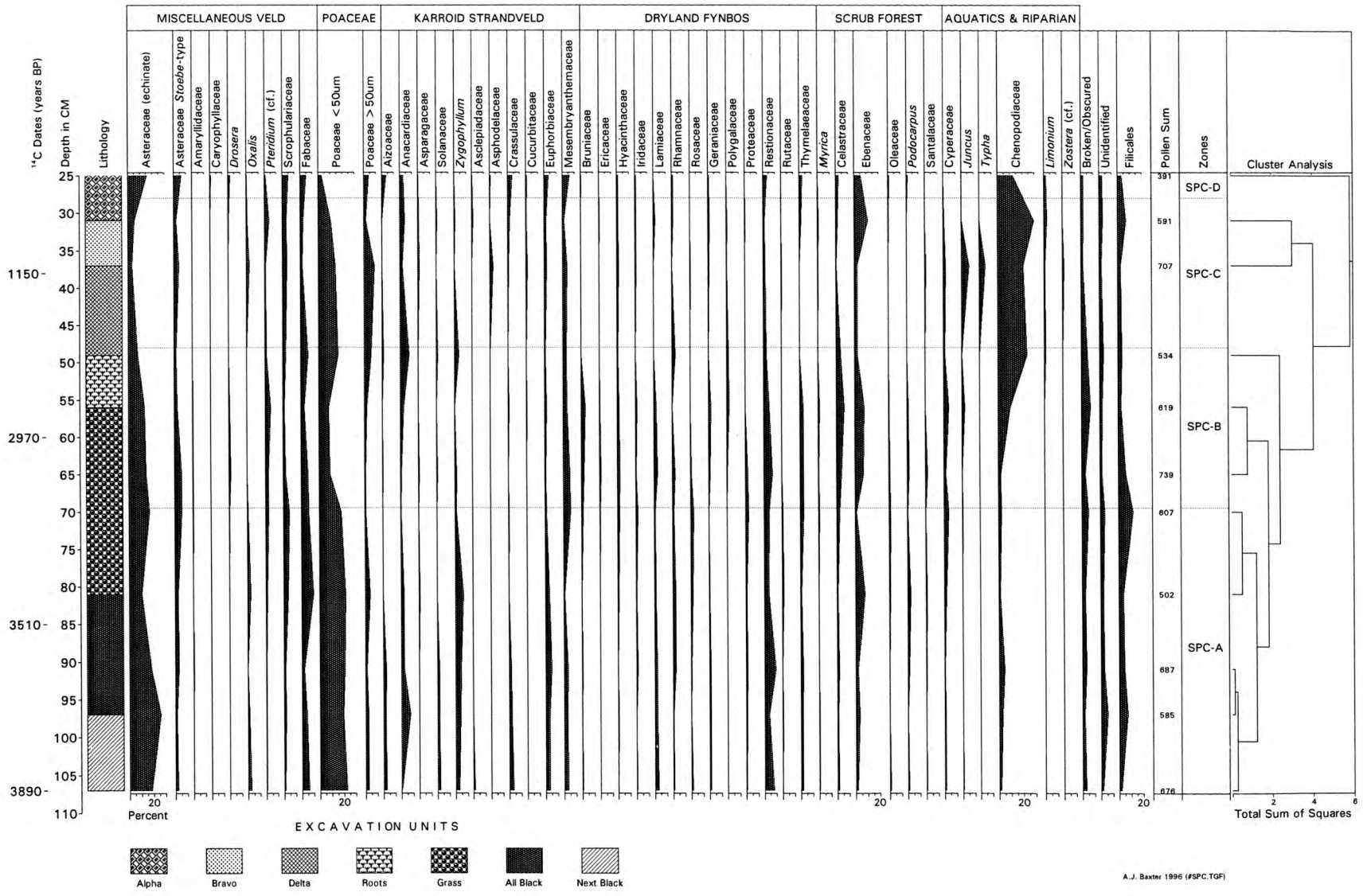
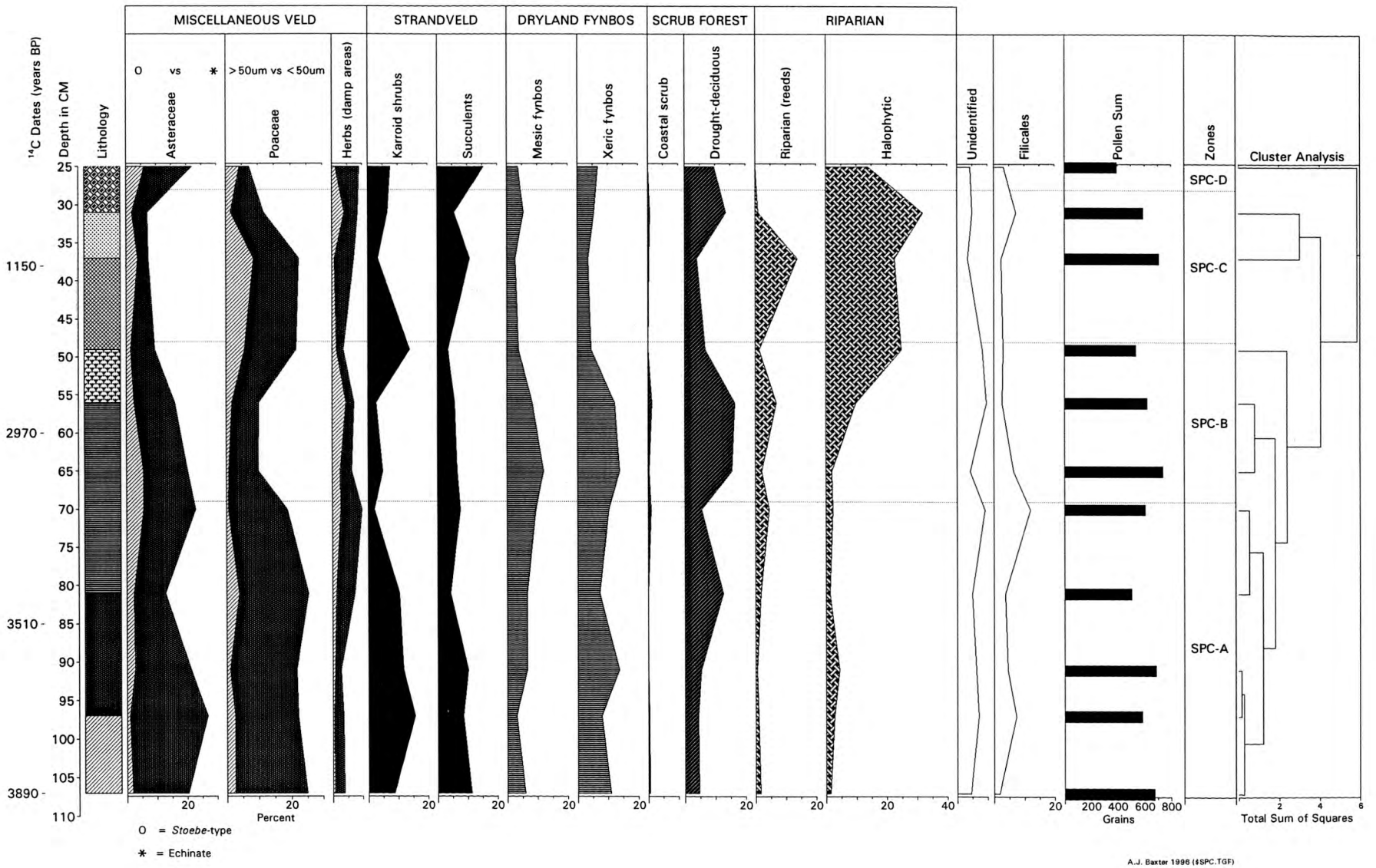


Figure 8.34 Spring Cave (SPC) summary (ECODE) pollen diagram



Zone SPC-B. Minor but significant fluctuations in the pollen spectra distinguish this brief assemblage zone. Extending from 68 cm (*circa* 3 200 BP) to the distinct stratigraphic boundary at 50 cm (*circa* 2 800 BP), this zone is estimated to represent approximately 400 years of sedimentation which effectively terminates with the commencement of the occupational hiatus first recognised by Miller *et al.* (1993). The spectra are characterised by elevated frequencies of mesic fynbos elements and Scrub Forest taxa. Among the fynbos, fossil pollen from Bruniaceae, Ericaceae Geraniaceae and Polygalaceae are noted from the Sandveld for the first time. Strandveld elements, with the exception of Mesembryanthemaceae, are not as abundant as the previous zone. Asteraceous types, including *Stoebe*-type, are seen to increase relative to the Poaceae, while *Pteridium* spores reach a small but significant peak in the middle of this zone. Chenopodiaceae increase substantially at the upper zone boundary, while riparian elements include *Juncus* pollen for the first time in the Spring Cave sequence.

Zone SPC-C. The third pollen zone incorporates the excavation horizons demarcated as; Foxtrot, Echo, Delta and Charlie, and spans the approximate 1 500 year occupational hiatus at the site. Among these comparatively sandy horizons, organic matter content falls below 4 % and pollen concentrations are low, averaging around 5 X 10^3 grains cm^{-3}. There is a pronounced increase in halophytes, mostly Chenopodiaceae, and a coordinated increase in Poaceae, including a substantial proportion of large grass palynomorphs. Echinate Asteraceae do not appear to be as prolific as in the previous zone, although *Stoebe*-type demonstrate consistent proportions. Towards the top of the zone, Scrub Forest and especially fynbos elements, including the ever-present Restionaceae, become less conspicuous. Strandveld taxa including, Anacardiaceae, Asphodelaceae, Crassulaceae, Euphorbiaceae and Mesembryanthemaceae are all reflected in the environment at this time. The riparian elements, *Juncus* and *Typha*, peak in synchronisity, with combined values of between 12 - 15 % of the spectra.

Zone SPC-D. The age of the sediments are not known for this zone, but they probably accrued during the last 500 years. The uppermost spectra from Spring Cave are distinguished by the absence of riparian taxa and a return of succulent vegetation. Restionaceae, Thymelaeaceae and a range of Scrub Forest elements show increased proportions. Ebenaceae pollen, especially, is abundant at this time. The increase in Asteraceae at the top of the sequence is consistent with all the other Sandveld sites for the same period.

8.7.2.1 *Palaeoenvironmental reconstruction of SPC*

The introduction and deposition of pollen in caves is strongly influenced by prevailing winds and slope direction (Weinstein, 1981). The alignment of Spring Cave indicates that the naturally arriving pollen should be broadly diagnostic of the vegetation growing on the steep sandstone slopes beneath the cave and from the coastal promenade that encompasses the lower reaches of Verlorenvlei. However, it is also recognised that the accumulation of pollen in archaeological sequences, such as Spring Cave, can be severely complicated by human bias. Among the known sources of potential contamination in Sandveld sites are: bedding material such as reeds and grass (Parkington, 1986; Parkington and Poggenpoel, 1987), edible plants, including geophytes and *Carpobrotus* (Liengme, 1987), and firewood (February, 1992), and all are anticipated to have been *selectively* introduced to Spring Cave at various times during the occupation of the site. The appropriateness of the Spring Cave pollen spectra as a reliable source of palaeoenvironmental information is, therefore, open to interpretation. While there is no way of distinguishing anthropogenic introductions from naturally occurring pollen, the study of sites such as Spring Cave as gross indicators of vegetation change are vindicated to some extent by the following factors. Firstly, it is recognised that the selective introduction of macrofossil plant remains (eg, fuelwood) does not equate, *senso stricto*, to the introduction of pollen from that taxa - unless there were pollen bearing flowers present. Secondly, human selection of plant material is naturally regulated by the prevailing environmental conditions which prescribe the availability of all taxa. This implies that, regardless of selective procurement, plant material (and any associated pollen) will be sampled primarily from the available, rather than the desirable, taxa. Thus, the regional palaeoenvironmental signal will not necessarily be compromised in the analysis of fossil pollen from such an archaeological context.

Following commencement of sedimentation at Spring Cave ± 4 000 BP until approximately 3 200 BP, conditions along the mountain slopes above Elands Bay appear to have been semi-arid - but not dissimilar to those today. Vegetation communities, strongly analogous to those which presently occur on Muishoekberg and around the Verlorenvlei krantzline, are suggested by the NNIs (Figure 8.35). This vegetation is indicative of spinescent, succulent and drought-resistant shrubby Strandveld. *Euclea, Zygophyllum, Rhus* and *Ruschia* are examples of probable woody taxa while herbaceous shrubs such as *Lessertia, Wiborgia* and *Salvia* would have constituted the understorey. Euphorbiaceae and Mesembryanthemaceae, possibly *Lampranthus* and *Carpobrotus* were ubiquitous. Grass pollen is abundant throughout the lower sequence and is assigned to common Strandveld genera such as *Erharta, Eragrostis*, and *Chaetobromus*.

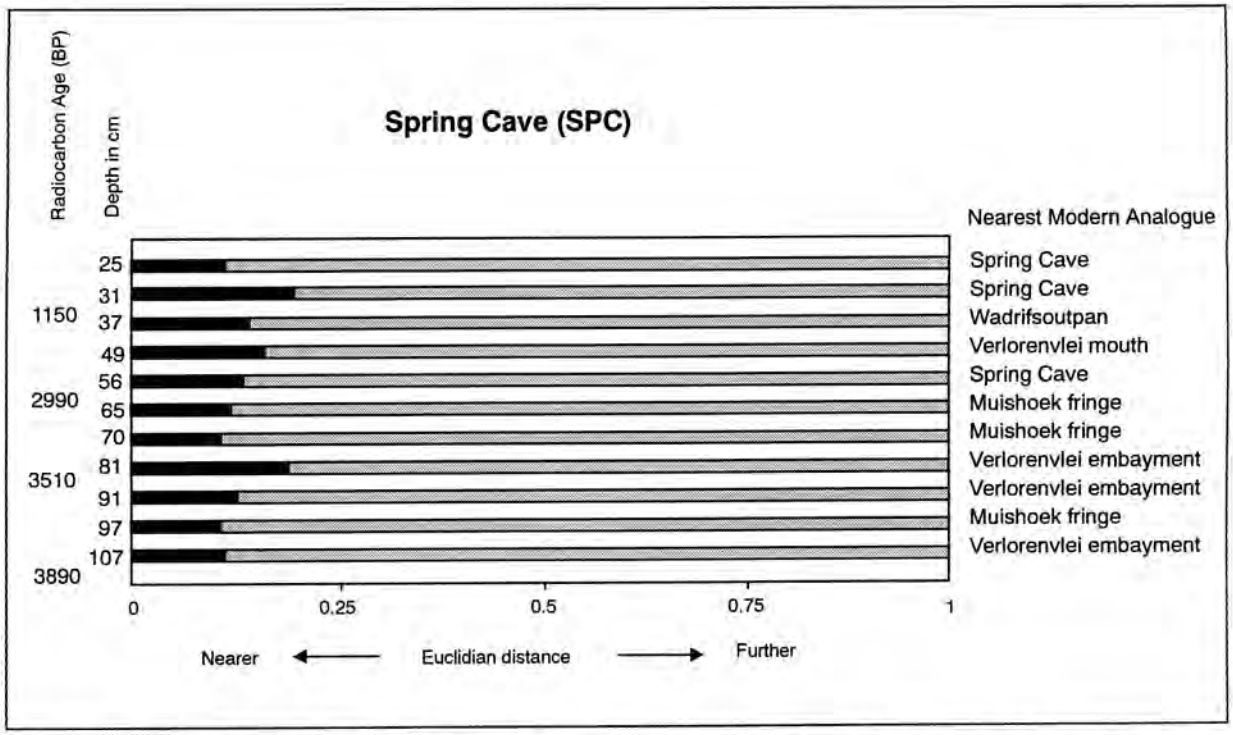
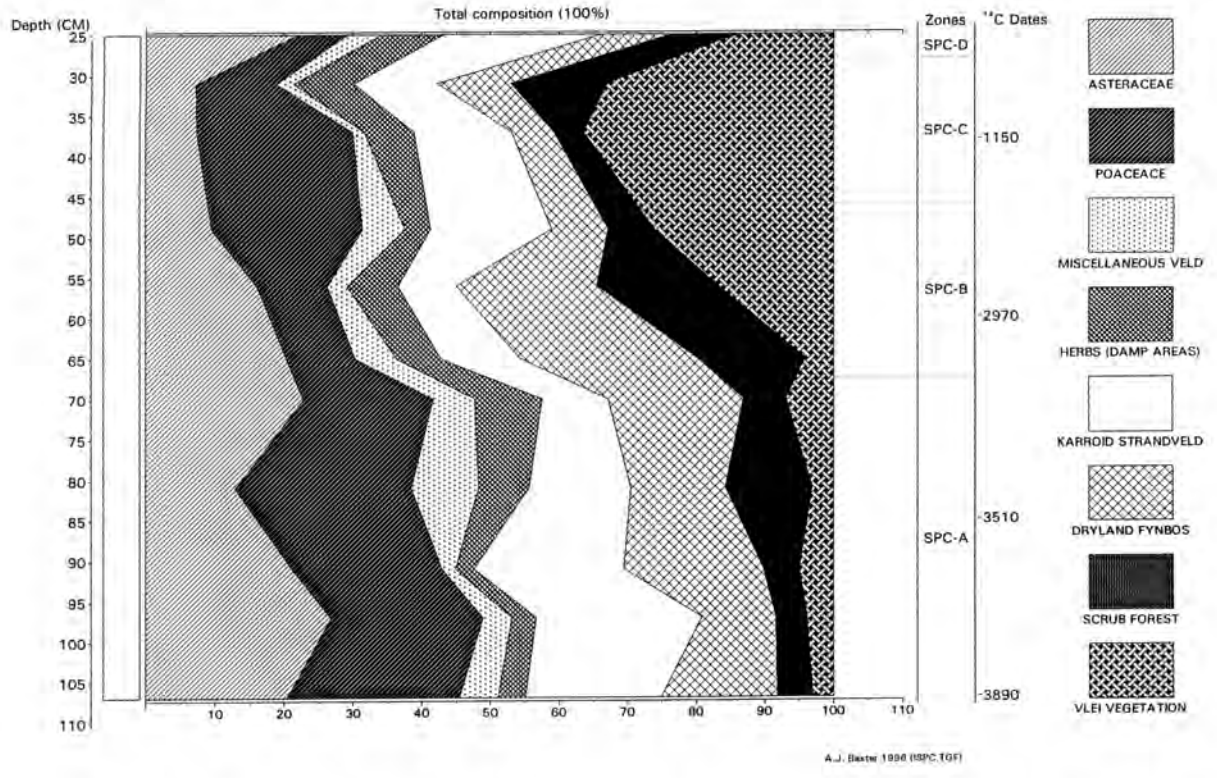


Figure 8.35 Nearest Neighbour Indices (NNIs) for the SPC pollen spectra. (Refer to Table 6.4 for a description of the analogue sites).

Asteraceous elements including *Eriocephalus, Pteronia* and *Senecio* are envisaged to have colonised the rocky coastal margin. Relative sea-levels were around 2 - 3 m amsl during this time period, resulting in degradation of the shoreline beneath Spring Cave (Yates *et al.*, 1986) The wave-cut platform which presently protects the modern shoreface and the sandy terrace to the west of the railway line (Figure 3.5) would have been inundated at this time, and the palaeoshore would have risen to the break of slope, parallel and not too far removed from the modern coast road (Yates *et al.*, 1986). In summary, there is little evidence for regional or even local moisture among the vegetation elements at this time, although towards the top of Zone SPC-A, around 3 500 BP, *Cyperus* pollen is observed to increase in tandem with *Pteridium* spores and may indicate rejuvenation of the seepage-spring at the rear of the cave.

Following 3 000 BP, a subtle diversification of the fynbos signal is recognised from Spring Cave. Drought-deciduous Strandveld taxa are replaced by unusual heath-like indicators such as *Brunia* and *Erica*, geophytes such as *Lachenalia*, shrubs such as *Pelargonium, Phylica, Cliffortia* and *Passerina* and, woody taxa such as *Protea*. The evidence points overwhelmingly to a brief period of enhanced moisture availability in the Sandveld. Notwithstanding the relative abundance of woody taxa such as *Maytenus, Diospyros* and *Euclea*, there are indications that the sheltered sandstone ravines were also supporting *Myrica*, an Afromontane Scrub Forest element. The poor Poaceae signal is interpreted either as a statistical aberration brought about by the marked increase in

Figure 8.36 Spring Cave (SPC) cumulative pollen diagram



minor elements (ie increased floristic diversity), or as a genuine decline in response to climatic amelioration and outcompetition by ecologically equivalent fynbos elements.

The period commencing with the occupational hiatus at Spring Cave is indicative of pronounced changes in the extralocal vegetation (Figure 8.36). Sometime between 2 800 and 1 500 BP, there is a massive influx in pollen from halophytes, including the Chenopodiaceae and possibly grasses such as *Sporobolus*. These spectra reveal NNIs which are very closely aligned to the vegetation of Wadrifsoutpan and the Verlorenvlei mouth (Figure 8.35). The relative consistency of the regional terrestrial pollen signal from the same spectra suggests that the increase in halophytes was either a response to localised adjustments in microclimate or to geomorphic changes brought about by sea-level fluctuations.

Cohen *et al.*, (1992) have identified a period of depressed sea surface temperatures (SSTs) at Elands Bay between 4 000 and 2 000 BP. Lower SSTs have been correlated to the intensification of coastal fog, and may have induced significant local climatic and edaphic changes around the coast at Elands Bay at this time. Cole and Liu (1994) attribute the increase in Cheno-Ams in the pollen record from an estuarine site in California to a greater incidence of coastal fog under depressed SST conditions during the late mid-Holocene. Certainly, an increase in Chenopodiaceae elements such as

Atriplex and *Sarcocornia* would be consistent with the development of saline soils beneath the cliffs on Bobbejaansberg. Evidence from Elands Bay Cave (Parkington, 1984) points to an increase in the accretion of halites and gypsum, coincident with the mid-Holocene, but there appears to be little supporting evidence from the complimentary sediments at Spring Cave. An alternative scenario for the observed increase in halophytes relates simply to the sea-level regression which followed the mid-Holocene high stand. A drop in relative sea-level, to a height comparable with, or slightly less than the present datum, would have re-exposed the rocky wave-cut platform to the southwest of the Verlorenvlei mouth. For some time, as the sea-level regressed, equilibrated and transgressed again, the platform would have acted as an emergent off-shore reef, allowing for the development of a shallow, saline lagoon in the lee of the rocky obstruction. It is possible that, at times, this lagoon was connected to the Verlorenvlei estuary and may have been subject to tidal influence. In addition, Miller et al. (1993), report on a relict dune that rises about 1 km north of Elands Bay village and trends northeast away from the present coastline to merge with the active dunefield to the north. This feature has been interpreted as a washover bar, or berm, that was active during the late Holocene (R Yates, personal communication). Sediments preserved behind the berm are suggestive of repeated washover episodes as the sea-level dropped and coastal progradation resumed. Implicit in this interpretation is the development of an extensive hypersaline back-barrier lagoon immediately to the north of Verlorenvlei and possibly draining into it.

On the basis of the changing geomorphology around the mouth of Verlorenvlei during the late Holocene, it is hypothesised that an extensive saltmarsh formed in the lee of the reef, beneath Spring Cave, and in the back-barrier lagoon to the north of the mouth. As a consequence, pollen from the predominant halophil vegetation have therefore come to be reflected in the sediments from this time. On account of their distinctive morphology, a small number of pollen grains (8 in total), towards the top of zone SPC-C, have been assigned to *Zostera*-type. *Zostera* (eel grass) pollen would not ordinarily be expected to survive prolonged diagenesis in a cave site, but the sediment sample is organic rich, and pollen from this level are well preserved. If, indeed, the identification is correct, then the interpretation of a saline lagoon or tidal estuary at the base of Bobbejaansberg becomes all the more convincing.

The most recent spectra from Spring Cave have accumulated during the course of the last millennium. The regional vegetation appears to have 'relaxed' back to a Strandveld signal with a greater proportion of woody drought-deciduous and succulent types than fynbos elements. Halophil vegetation remains well represented indicating the

persistence of hypersaline conditions near the vlei mouth. Asteraceae may be indicative of disturbances such as fire and selective overgrazing.

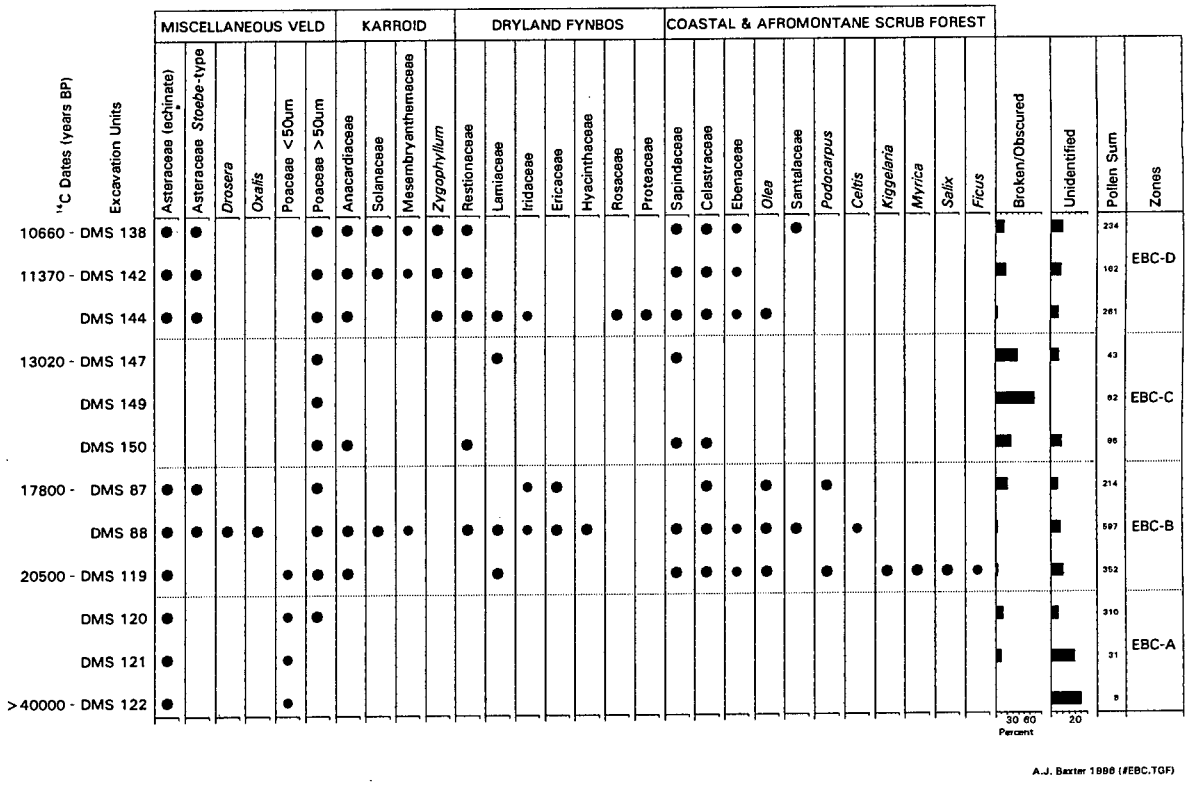
8.8 Elands Bay Cave

Elands Bay Cave has been the subject of an intensive investigation of both the human-cultural and palaeoenvironmental record (Parkington, 1981). The site carries the distinction of preserving sediments which span the late Pleistocene and Holocene, and, most importantly, encompass the Last Glacial Maximum. Naturally accumulating sediments of this age have not been encountered anywhere else in the Sandveld or, for that matter, from anywhere in the southwestern Cape. The analysis of fossil pollen, from the oldest occupation layers at Elands Bay Cave, has produced the first preliminary image of the regional vegetation history of the Sandveld region, commensurate with the Last Glacial Maximum.

8.8.1 The Elands Bay Cave (EBC) pollen diagram

From the Bulk samples originally collected during the 1980 excavations, 19 units were made available for analysis (refer to Table 6.3 for excavation details). Preliminary assessment revealed that 7 units were technically devoid of pollen and these samples were abandoned. From the 12 remaining bulk units, large subsamples, in the order of 100 - 200 g of sediment, were selected for fossil pollen preparation. The sediments demonstrate considerable variability in their physico-chemical composition and this resulted in numerous methodological complications. In this regard, the author is especially grateful for the assistance of N Erlanck during the lengthy preparation procedure. All the samples were subjected to an initial treatment in hydrochloric acid to dissipate calcium carbonate, gypsum and sulphate precipitates. Following gentle maceration, samples were sieved to remove coarse, macroscopic particulate matter and then split into multiple subsamples so as to be accommodated in standard laboratory ware. Conventional procedures of pollen concentration were then applied (Appendix C). As with the Spring Cave samples, the preponderance of charcoal and ash in the sequence presented a number of problems. In some instances, the palynomorphs appear to have become 'welded' to dense charcoal flocs, an indication perhaps, of post-depositional sintering. Deflocculation of the clay fraction with sodium hydroxide and the digestion of organic detritus by means of acetolysis, is thought to have been detrimental since, in some instances, prolonged oxidation has resulted in corrosion

Figure 8.37 Elands Bay Cave (EBC) pollen-presence diagram



of all but the most resilient pollen grains. For each sample, trial and error was required to achieve a balance between sample purification and pollen preservation. ultimately, all 12 samples produced fossil palynomorphs of some description, although pollen concentration varied between 6 X 10^3 grains g^{-1} in DMS 88, to as few as 3 X 10^1 grains g^{-1} in DMS 122. As a result, pollen counts were generally low and extremely variable (Appendix F). Poor statistical reliability, especially towards the bottom of the sequence, coupled with the wide chronological interval between samples, mitigated against the construction of a resolved pollen diagram. To counteract the bias associated with unreliable pollen counts, the data are presented, unambiguously, in a 'presence' diagram. This format illustrates patterns in the pollen assemblage without focusing attention on proportional representation. The Elands Bay Cave (EBC) pollen-presence diagram (Figure 8.37) provides a useful summary of those taxa which, according to their pollen signature, are positively correlated to the vegetation growing in the extralocal and regional landscape at the time of deposition. No inferences can be made about the dominance of one taxon over another and no inference can be made about taxa not being present in the landscape, since their absence in the spectra may simply be an artefact of poor preservation or inadequate pollen counting. Nevertheless, the EBC pollen sequence provides a useful indication of vegetation composition in the vicinity of the cave during the Last Glacial Maximum and through the period spanning post-glacial

amelioration until the onset of the Holocene, at 10 000 BP. Four pollen assemblage zones have been identified, subjectively, to aid in the description and interpretation.

Zone EBC-A. The oldest sample, DMS 122, from the base of the sequence, has returned an infinite date of > 44 600 BP (Pta 5334). The radiocarbon ages of samples DMS 121 and DMS 120 have not been established but they too are assumed to be of late Pleistocene age. Pollen concentration is extremely low and many palynomorphs are broken, crumpled or corroded. More than 25 % of the pollen was unrecognisable and is thought to belong to taxa which are no longer endemic to the Sandveld or fynbos regions of the southwestern Cape. In total some 260 pollen grains were identified from these three levels and, almost without exception, they have been assigned to the echinate Asteraceae and Poaceae. The Poaceae pollen is similar, in some respects, to modern *Phragmites* pollen: small in size with indistinct pore structures. The general morphological consistency of this pollen type suggests that it may be the product of a single Poaceae taxon. In general, very little palaeo-interpretative meaning can be deduced from these two pollen taxa except that grassy species may have been in abundance. In contrast to all the other samples from Elands Bay Cave, the sediments from these three lowermost samples produced very little effervescence during the processing procedure, an indication that carbonates and gypsum are not a characteristic of these levels.

Zone EBC-B. Incorporating samples DMS 119, DMS 88 and DMS 87, the pollen from these layers accumulated some time between 20 500 ± 240 BP (Pta 5304) and 17 800 ± 180 BP (Pta 5308). Despite low levels of pollen concentration, there is an astonishing array of different pollen types from this time period. Most noteworthy are the Afromontane Scrub Forest elements which reflect good representation from the Ebenaceae and Celastraceae but also include diverse taxa such as *Dodonaea, Kiggelaria, Podocarpus* and *Olea*. Fynbos taxa such as Restionaceae, Iamiaceae, Iridaceae and Ericaceae pollen is present but, surprisingly, no Proteaceae. Sample DMS 188 contains pollen from karroid indicators such as Anacardiaceae, Solanaceae and Mesembryanthemaceae. For the assemblage zone as a whole, Poaceae pollen (of the more conventionally recognised variety) is the most predominant element - although this statistic is not reflected in the pollen diagram. Asteraceae pollen is present in all samples - but only in small proportions.

Zone EBC-C. Samples DMS 150, DMS 149 and DMS 147 accumulated between 17 800 and 13 020 ± BP (Pta 6757). The only justification for an independent assemblage zone for these spectra is that a large proportion (up to 60 %) of all the visible palynomorphs were

damaged, corroded or obscured beyond recognition. Since no 'new' taxa are recorded from this zone, there is no scientific basis upon which to assume that any significant change in the vegetation took place. Rather, preservation conditions in Elands Bay Cave appear to have been compromised during this period.

Zone EBC-D. The final zone extends from *circa* 13 000 BP until 10 660 ± 100 BP (Pta 5369). The uppermost samples, DMS 144, DMS 142 and DMS 138 show improved levels of pollen concentration, reflected in enhanced levels of identification. The spectra demonstrate a range of drought-deciduous Strandveld and Dryland Fynbos elements, among which *Heeria, Rhus, Zygophyllum, Maytenus, Putterlickia, Dodonaea, Diospyros* and *Euclea* are considered to be the most likely genera.

8.8.1.1 *Palaeoenvironmental reconstruction of EBC*

Pollen is not very abundant in Elands Bay Cave, a situation which is congruous with the observations gained from the neighbouring site of Spring Cave. Poor pollen preservation is attributed partly to the age of the sediments and partly to the fact that archival bulk samples, derived during the 1980 excavations, were not originally collected with the specific intention of pollen analysis. As such, the dry, unrefrigerated samples may have deteriorated as a result of enhanced oxidation and post-excavation diagenesis. Nevertheless, fossil pollen representation is sufficient to warrant a modest attempt at environmental reconstruction. Broadly speaking, the range of pollen types observed is not very well correlated with the natural vegetation communities which today characterise the Elands Bay region - as evidenced by the large distances in the NNIs (Figure 8.38) - and there are variations in community structure which suggest that significant environmental changes occurred during the sedimentary period.

Pollen Zone EBC-B is particularly noteworthy, as it is approximately contemporaneous with the Last Glacial Maximum and therefore indicative of conditions at the time of one of the extremities of the glacial-interglacial cycle. Here the pollen frequencies of Afromontane Scrub Forest taxa achieve greatest diversification. (It should be noted that arboreal pollen (AP) constitutes some 25 - 30 % of the spectra in this zone). Some of these taxa, such as *Celtis, Myrica, Podocarpus* and *Kiggelaria* are currently scarce, rare or absent in the Sandveld region today. The NNIs for these spectra (Figure 8.38) show that almost no correlation exists between the Last Glacial vegetation at Elands Bay Cave and the modern range of Sandveld vegetation communities, although it may be significant that the upland vegetation from Piketberg is routinely among the nearest of the very distant neighbours. Most of the Afromontane and coastal Scrub Forest elements,

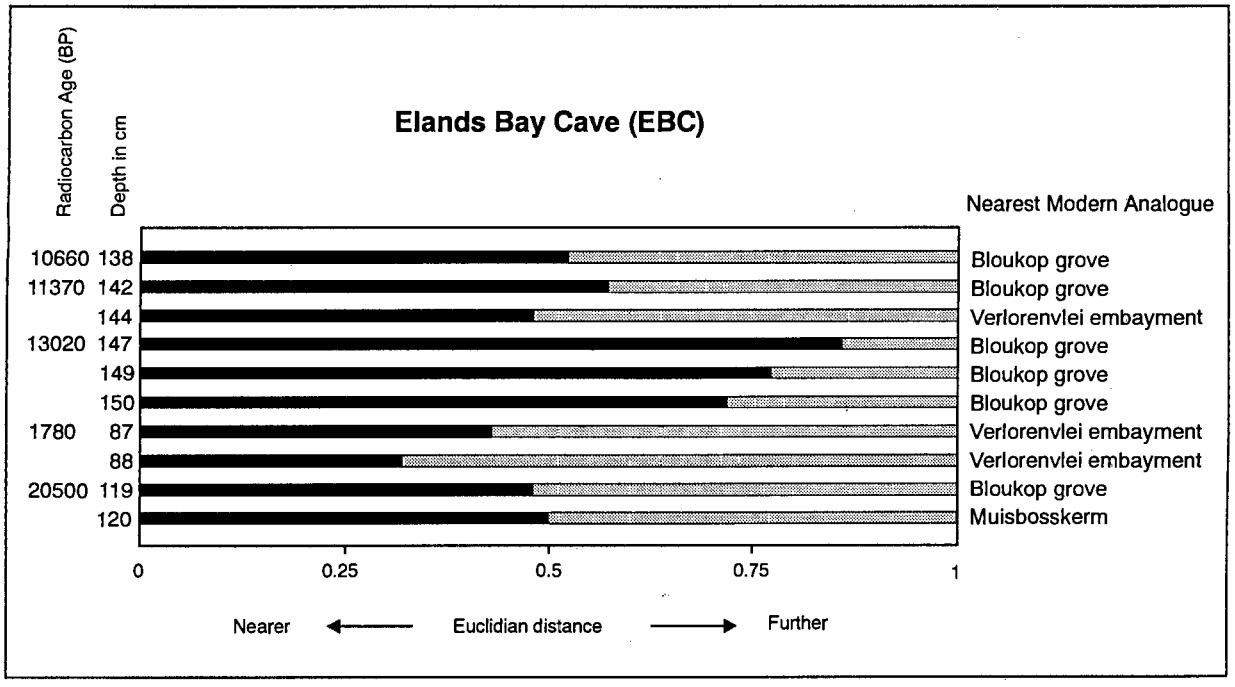


Figure 8.38 Nearest Neighbour Indices (NNIs) for the EBC pollen spectra. (Refer to Table 6.4 for a description of the analogue sites).

including the Ebenaceae and Celastraceae, are today found only in small patches associated with moister, sheltered habitats in the Sandstone koppies or among damp inter-dune depressions. The distinctive presence of these diverse woodland indicators points strongly to a more mesic and probably cooler situation at the time of the Last Glacial Maximum. Concentrations of total pollen also reach a maximum around this level, a feature which is consistent with the prevalence of lower temperatures, reduced evaporation and greater moisture availability in the vicinity of the cave.

For the sake of simplicity, it is tempting to assign the observed vegetation pattern at Elands Bay Cave to the influence of regional climates in response to the Last Glacial Maximum (eg, Deacon and Lancaster, 1988). However, it is also important to consider the influence of local geomorphic responses to glacio-eustatic sea-level change. Depressed sea-levels at the time (–110 m amsl) would have extended the coastal plain westwards by some 30 - 40 km (Tankard and Rogers, 1978; Parkington, 1986) and would have temporarily removed the influence of coastal vegetation communities from the sampling jurisdiction of Elands Bay Cave. Furthermore, the distance from the sea, combined with the relative elevation in topography of the Bobbejaansberg massif, may have resulted in enhanced levels of orographic rainfall in the vicinity of the cave. A contemporary analogy for such a situation can be drawn from a biogeographical comparison of the uplands of Piketberg, some 50 km inland of Elands Bay Cave. Today, the Piketberg receives three to four times the average rainfall of the Sandveld plains to the west. Here, the upland slopes support a mixture of mesic and xerophytic fynbos

elements, more typical of the Cape Fold Belt, while the well-watered kloofs and gullies shelter dense thickets of Afromontane Scrub Forest (personal observation). While there can be no clarity as to the exact mechanism behind the climatic response to the Last Glacial Maximum around Elands Bay Cave, there is greater certainty that this part of the Sandveld was subject to cooler and possibly wetter climatic conditions at the time. Coincidentally, the area currently occupied by the Verlorenvlei coastal lake would have been a deeply incised floodplain, occupied by a perennial river fed by the increased precipitation in the mountains of its catchment.

Subsequent vegetation changes are also apparent. Although pollen preservation is particularly poor in zone EBC-C, which encompasses the latter part of the Last Glacial Maximum, frequencies of identifiable pollen revive again in zone EBC-Dd dating to the terminal Pleistocene. The presence of pollen belonging to the Anacardiaceae, Mesembryanthemaceae, *Zygophyllum* and Solanaceae are typical of the Strandveld communities of the present day, and document rather drier and warmer conditions than had prevailed in the full glacial. Pollen counts reveal that Poaceae are the most abundant contributors to these pollen spectra while Asteraceae pollen is only a very minor constituent of the pollen sum. There are convincing indications, reflected in the archaeology of Elands Bay Cave, towards the terminal Pleistocene (Parkington *et al.*, 1988), that sea-level was rising in response to post-glacial climatic amelioration and glacial melt - although it is doubtful that the coastal plain would have been entirely inundated at this time. The overall pollen signature suggests that a xerophytic grassy Strandveld-type community occupied the coastal plains to the west of the cave. Increased halites and carbonates in the sediments suggest that coastal fog and increased aridity may have been factors at this time.

It is interesting to note that Cartwright and Parkington (unpublished data) are involved with the systematic analysis and identification of archaeological charcoals from Elands Bay Cave. Preliminary charcoal results are expected for the period spanning the Last Glacial Maximum until the late Holocene. Fossil charcoals are an integral component in most archaeological sites and present, therefore, a valuable palaeobotanical resource (Sander and Gee, 1990). The method of charcoal analysis, as described by February (1992) for neighbouring Sandveld sites including Spring Cave, attempts to identify and quantify charcoal remains as indicators of former (woody) vegetation types. Implicit within the analysis of charcoal from archaeological hearths, is the expectation that considerable bias may have come to be inherited through selective human fuel choice. Notwithstanding these limitations and despite the methodological and philosophical differences between the two techniques, both fossil pollen analysts and fossil charcoal analysts base their interpretations on the presumed availability of (woody) plants in a

climatically supportive landscape. From this perspective, it will be interesting to compare the fossil pollen data (presented here, for EBC) with the fossil charcoal data (pending) of Cartwright and Parkington.

8.9 Verlorenvlei Cottage core

The final set of palaeoenvironmental observations comes from the Verlorenvlei Farm embayment and the site of the Verlorenvlei Cottage core (VCC). The core was retrieved by the author in the hope that it would provide information on the geomorphological history of the distal reaches of Verlorenvlei and, possibly, shed new light on the sedimentary discontinuities reflected in the Grootdrift and Klaarfontein cores, located at the proximal end of the system. Given the apparent complexity of Holocene sea-level fluctuations along the West Coast, it was envisaged that cores from the lower-middle reaches of Verlorenvlei might reflect the interbedding of fresh water and marine sediments. Transitions from fresh water to overlying marine sediments would imply inundation by the sea and are referred to as ingression contacts (Anundsen *et al.*, 1994). So-called isolation contacts occur when sea-levels regress to leave the basin isolated from the sea. Such events have been used by Anundsen *et al.* (1994) to describe estuarine sedimentation in southeast Australia during the Holocene. A subsidiary objective (though not directly affiliated to this thesis) was to evaluate the suitability of the sediments for the analysis of fossil ostracods. Given sufficient densities of identifiable fossil carapaces, a palaeolimnological reconstruction was to be initiated. To date, the author has been a participant in two surveys of contemporary ostracod fauna from Verlorenvlei for the purpose of assimilating data on the distribution of modern taxa (refer to Martens *et al.*, 1996) but, as yet, the expertise to conduct the fossil ostracod analysis has not been forthcoming. In the interim, the sediments from the Verlorenvlei Cottage core were made available to J van der Vlugt for analysis of the sedimentology. Although preliminary results of this work have been presented elsewhere (van der Vlugt, 1994) no meaningful interpretation was entered into. A complete reassessment of the sedimentology of the Verlorenvlei Cottage core has recently been attempted by the author. New data in the form of a detailed stratigraphic description, radiocarbon chronology and the first detailed assessment of *in situ* molluscan fauna are used to substantiate the textural analysis and aid in the geomorphological interpretation. In addition, comparisons are drawn between the sedimentology of the Verlorenvlei Cottage core and the Grootdrift GDN borehole from which new evidence surrounding the sequence of relative sea-level change along the West Coast is presented.

8.9.1 Stratigraphy and chronology

The Verlorenvlei Cottage vibracore produced 6.92 m of core material, terminating on a dense shell lens of unverifiable origin but thought to be *Psammotellina capensis* (personal observation). The core log (Figure 8.39) discloses a consistent basal sequence of well-sorted inorganic sands which extend up to 5.87 m. At this depth, the compact sand facies suddenly gives way to a cohesive greenish-grey 'gley' clay-mud matrix. This facies is structurally and visually coherent and extends up for approximately 1 m, until 4.94 m, where an abrupt departure to fine grey sand occurs. The base of the clay-mud has returned an age of 7840 ± 110 BP (Pta 6596) while the top of the mud is dated to 7430 ± 80 BP (Pta 6155). Both dates are accompanied by $\delta^{13}C$ values of -19.7 ‰, which suggest isotopic enrichment, probably by marine water. In such instances, the radiocarbon dates may need to be corrected for the apparent age of sea water by subtracting 400 years (eg, Miller *et al.*, 1993). However, for the purposes of this discussion, and to maintain continuity with the isotopically enriched dates from VCC, GDN/GDV1 and KFN, the ages have not been adjusted for sea water. Allowing for the fact that the dated samples from VCC are from inside the stratigraphic boundaries of the clay-mud facies, the estimated age of deposition is likely to be in order of 8 000 to 7 200 BP. Further up the core, between 2.86 and 2.60 m, there is a second, albeit abbreviated, clay-mud phase of broadly similar appearance to the earlier event. A date of 5490 ± 80 BP (Pta 6591) was derived from the upper margin of this facies and the $\delta^{13}C$ value of -20.2 ‰ suggests that it might also be the product of a marine phase, sometime around 5 500 BP. Between the two clay-mud episodes, the sediments are of a consistent amorphous grey sandy appearance - except for a discontinuity between 4.15 and 3.90 m, where there is a brief occurrence of fine white, very well-sorted material. Above the upper clay-mud layer, fine to medium brown sands, interspersed with yellow ochrous root and clay nodules, extend up to moderately sorted white sands at 80 cm. The uppermost sediments are muddy and distinctly organic, with dense associations of macrophytic *Phragmites* detritus and root material, becoming more fibrous towards the surface. Following progressive desiccation of the exposed core material, halites were observed developing as gross crystalline formations in among the brown sand and clay layer, between 2.0 m and 80 cm. Halite precipitation to this extent was not evident elsewhere in the core. The rate of sedimentation of the age-bracketed clay-mud layer is 1.6 mm $year^{-1}$, while the sediments which intervene between the first and second clay-mud layers, ie between 7 430 BP and 5 490 BP, accumulated at an average rate of 1.2 mm $year^{-1}$. The final 2.60 m of sediment accumulated at an average rate of 0.47 mm $year^{-1}$ and this suggests that either a sedimentary hiatus occurred at some time during the past 5 000 years or a large volume of sediment, the equivalent of 3 - 4 m in vertical depth, has been eroded from the system.

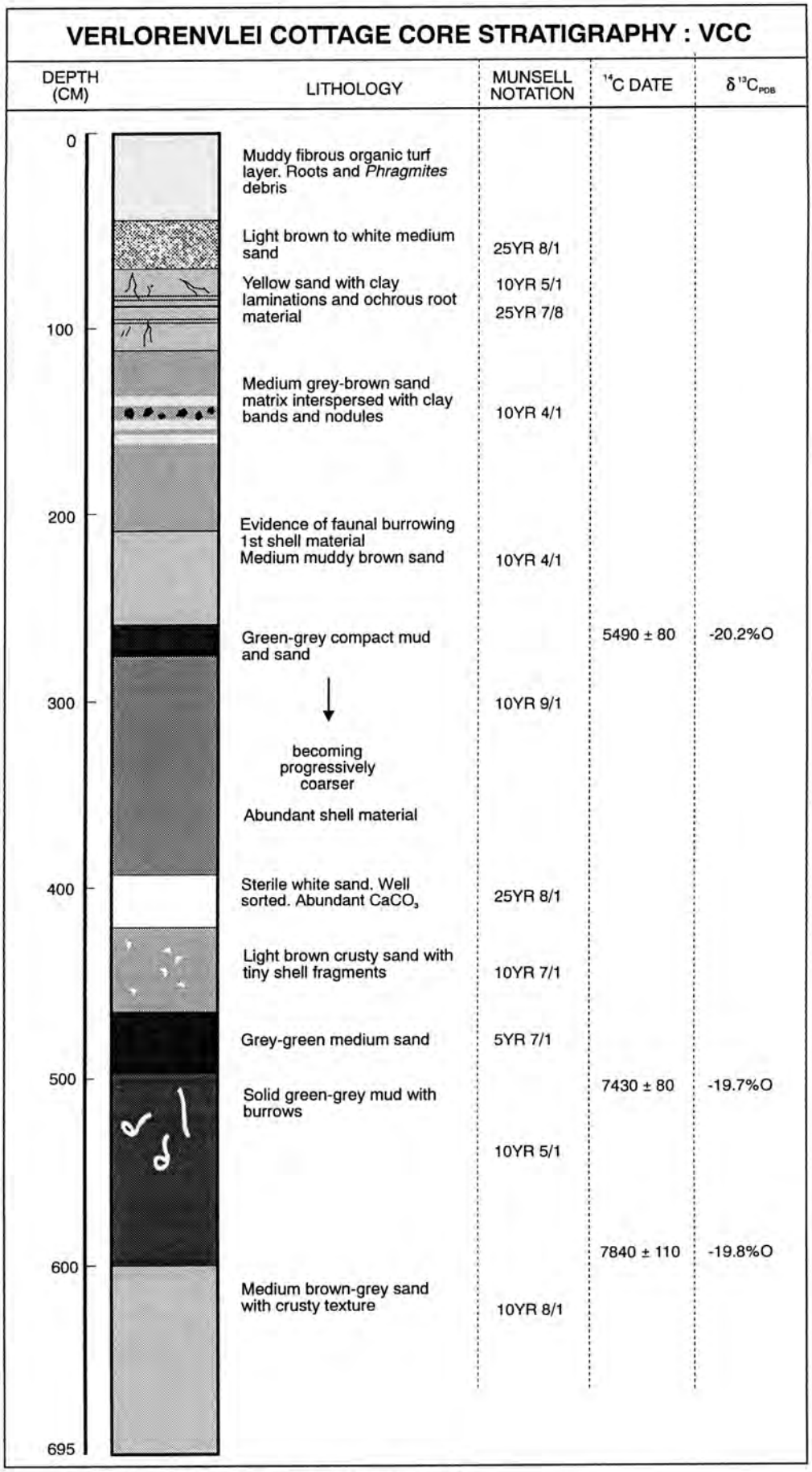


Figure 8.39 Verlorenvlei Cottage core stratigraphy : VCC.

8.9.2 Sedimentology and textural analysis

Sediment subsamples were chosen from either side of obvious stratigraphic transitions along the length of the core. Prior to analysis by J van der Vlugt, all 18 samples were dialysed by osmosis to remove salt from the samples which would otherwise introduce a weighing error to the dried sample mass. The coarse fraction (sand and gravel particles lager than 63 μm) was separated from the mud fraction (silt and clay) by wet sieving. Particle size analysis (eg, Tucker, 1988) of the sand fraction was conducted using a semi-automated hydraulic settling tube (this method is described in detail by Flemming, 1977a). Grain sizes are expressed in terms of the Wentworth scale and logarithmic Phi (ϕ) sizes (refer to Leeder, 1988). Results of the sedimentological and textural analysis are presented in Table 8.3. and Figure 8.40.

cm	CORE	NO.	MEAN ϕ	MEDIAN ϕ	MODE ϕ	SORTING	SKEWNESS	KURTOSIS
32		1	2.11	2.13	2.18	0.59	-0.07	1.08
48		2	1.92	1.94	2.07	0.55	-0.07	1.08
70		3	2.05	2.05	2.15	0.49	0.00	1.08
100		4	2.02	2.02	2.10	0.47	0.00	1.10
200		5	1.84	1.83	1.80	0.46	+0.03	1.17
235		6	1.87	1.87	1.90	0.41	+0.01	1.18
265		7	2.08	2.06	2.05	0.48	+0.05	1.09
292		8	2.28	2.30	2.38	0.44	-0.04	0.97
345		9	2.24	2.24	2.27	0.44	-0.02	1.17
388		10	2.43	2.42	2.40	0.34	+0.04	1.15
400		11	2.15	2.15	2.18	0.31	+0.02	1.16
460		12	2.59	2.59	2.57	0.37	-0.04	1.29
470		13	2.68	2.68	2.65	0.38	-0.06	1.31
490		14	2.57	2.57	2.55	0.38	-0.04	1.33
500		15	2.72	2.78	2.78	0.65	-0.16	1.14
585		16	2.55	2.51	2.35	0.61	+0.05	1.08
595		17	2.06	2.07	2.20	0.48	+0.04	1.14
690		18	1.98	2.02	2.18	0.50	-0.08	1.16
Active Beach			0.93			0.29	+0.56	0.67
Modern Dune			1.29			0.73	+0.43	3.19

Table 8.3 Results of the settling tube analysis from Verlorenvlei Cottage core. (Adapted from van der Vlugt, 1994). Analogue beach and dune data from Verlorenvlei are borrowed from Miller (1987). Important shifts in textural parameters are highlighted in black.

Figure 8.40 illustrates the gravel, sand and mud (GSM) ratios and the mean and sorting curves plotted for 18 different intervals from the Verlorenvlei Cottage core. From the graph it is evident that there are significant fluctuations in the mud fraction (silt and clay) throughout the core profile. The basal sediments have only a minor compliment of mud

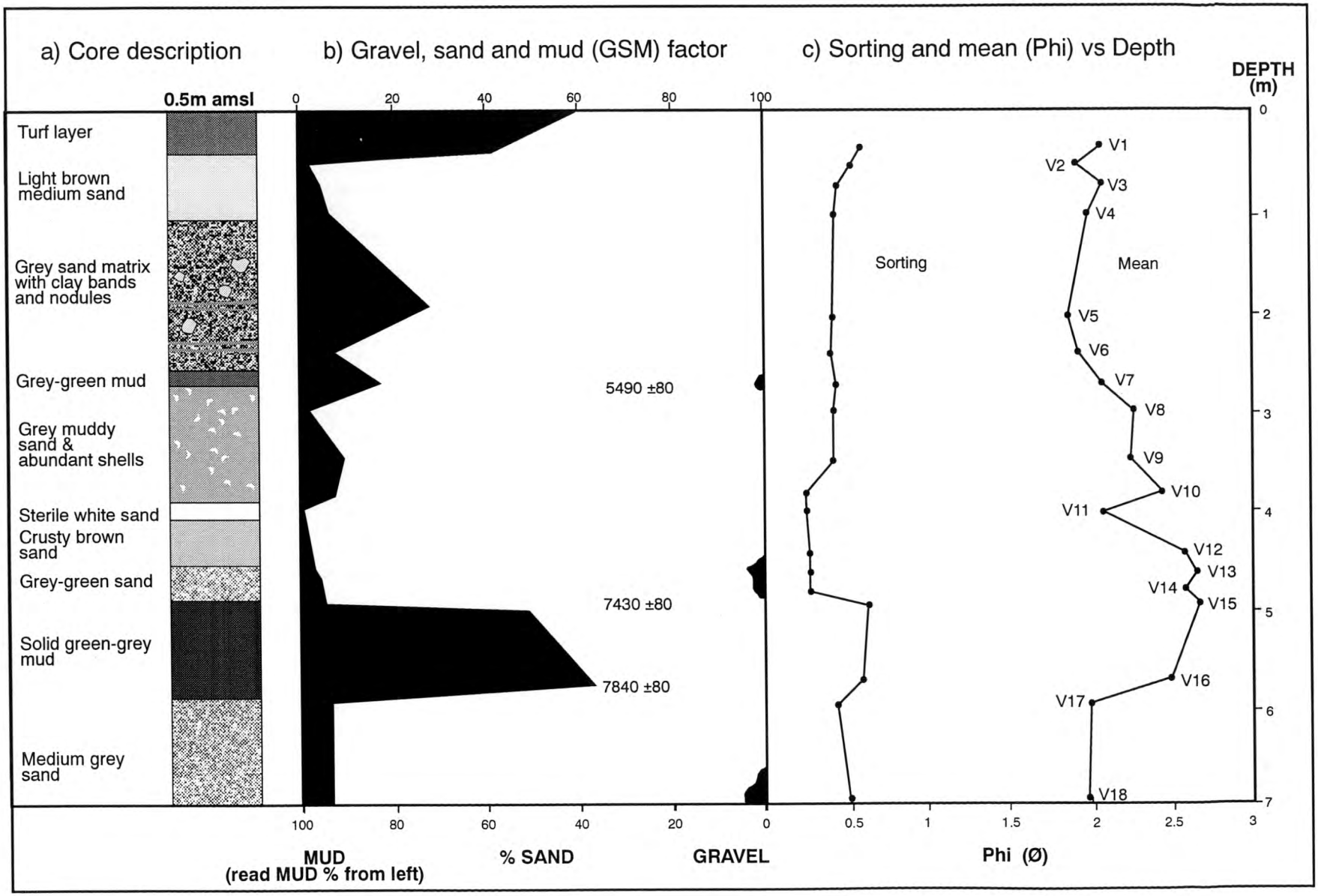


Figure 8.40a-c Core log and textural analysis of VCC.

and are dominated by well-sorted, medium sized sands and are strongly suggestive of a high energy depositional environment such as an active estuary (Lindholm, 1987). The sample at 5.85 m, heralds a pronounced peak in silt and clay (up to 65 %) which extends up to 5.00 m and corresponds with the greenish-grey mud facies first referred to in the stratigraphic description. In general, the sediments from the mud layer are moderate to poorly-sorted and negatively skewed (indicating a fine sediment with a coarse tail). The mean grain size of the sand fraction from sample 15 (Table 8.3) reveals that the finest sands (2.72 ϕ) also occur in this layer. The coarse (gravel) fraction of sample 13 consists solely of shell fragments and may indicate a change to a higher energy depositional environment. By all accounts, the green-grey mud deposit must have accrued in Verlorenvlei fairly rapidly (over a period of 5 - 600 years), probably during a low energy phase associated with a sheltered open water lagoon. Following the mud phase, a rapid shift in sedimentology is noted as the mud fraction declines to naught and the sand fraction becomes progressively better sorted. By 4.00 m, the standard deviation is considerably reduced, indicating a very well-sorted deposit. The mean, median and modal grain size is clustered around 2.15 ϕ and the sample is positively skewed. These attributes are consistent with a high energy phase of aeolian deposition (Dackombe and Gardiner, 1983) and signal the temporary exposure of the Verlorenvlei Farm embayment to terrestrial processes. Samples from 3.45 m to 2.00 m reveal fluctuating proportions of fine and sandy fractions. Mean grain size becomes progressively coarser up the sequence, although samples remain well-sorted. The textural analysis of this part of the sequence is suggestive of an ingression contact and the progressive re-establishment of an active estuarine environment, with tidal influence, in proximity to the site. The increasing mud fraction in sample 5 (at 2.00 m) is consistent with the establishment of a deeper water estuary at this time (Pethick, 1984). Despite the cohesive and shear strength advantage of the mud fraction in these deposits, a significant erosional event is hypothesised to have occurred in response to the progressive isostatic equilibration of the subcontinent following the mid-Holocene high sea-level stand. Despite the presence of biogenic carbonate, no whole molluscs of any description are found above 2.15 m and it is possible that riverine-estuarine conditions prevailed for some time after this, and that the mouth of the vlei migrated some distance to the south to occupy its present position behind the rock bar (Miller, 1987). The surface sediments reflect an increasing mud fraction - a factor attributed to the progressive sedimentation of the system in response to the seasonally closed estuarine lake.

8.9.2.1 *Palaeoecology of the fossil Mollusca*

Fossil Mollusca are abundant throughout the lower two thirds of the Verlorenvlei Cottage core but do not occur in recognisable quantities above 2.15 m. From the length of the lower sequence, large fragments and whole Mollusca were carefully extracted by the author and submitted to Prof C Griffiths of the University of Cape Town and J Pether of the South African Museum for identification. The taxa, their preferred habitat, and their distribution through the core are presented in Table 8.4.

cm	CORE	MOLLUSCA	HABITAT	SUBSTRATE / TIDE LEVEL
top		NO MOLLUSCA IN TOP 2		ABUNDANT HALITES
215		*Protomella capensis*	**Sheltered embayment**	Subtidal sandbanks from LWS* down to 3m
265		*Protomella capensis*	**Sheltered embayment**	Subtidal sandbanks from LWS down to 3m
275		*Psamotellina capensis* -	**Estuarine embayment**	Extra-limited thermophilic bivalve preferring -
		fragments ?	**Estuarine embayment**	Shallow, subtidal sandy estuarine substrates
335		*Choromytilus meriodionalis*	**Direct marine surf**	Exposed intertidal rocky shores and reefs
		Crepidula porcellana	**Sandy surf beach**	Exposed sandy beaches, subtidal
360		*Choromytilus meriodionalis*	**Direct marine surf**	Exposed intertidal rocky shores and reefs
		Venerupis corrugata	**Marine embayment**	Infratidal to subtidal sandbanks & rock pools
390		*Macowa crawfordi*	**Estuary**	Subtidal sand banks
		STERILE SAND		
420		abundant shell fragments	**High energy regime**	Possible wave or fluvial action
455		*Choromytilus meriodionalis*	**Direct marine surf**	Exposed intertidal rocky shores and reefs
460		*Argobuccinum pustulosum*	**Direct marine surf**	Rock crevices, intertidal to subtidal
470		*Venerupis corrugata*	**Marine embayment**	Infratidal to subtidal sandbanks & rock pools
560		*Protomella capensis*	**Sheltered lagoon**	Subtidal sandbanks from LWS down to 3m
		Venerupis corrugata	**Marine embayment**	Infratidal to subtidal sandbanks & rock pools
587		*Choromytilus meriodionalis*	**Direct marine surf**	Exposed intertidal rocky shores and reefs
599		*Nassarius plicatellus*	**Marine embayment**	Sheltered subtidal sandbanks
		Protomella capensis	**Sheltered lagoon**	Subtidal sandbanks from LWS down to 3m
628		*Psammotellina capensis*	**Estuarine embayment**	Extra-limited thermophilic bivalve preferring -
690		*Psammotellina capensis*	**Estuarine embayment**	Shallow, subtidal sandy estuarine substrates.

Table 8.4. Mid-Holocene Mollusca from the Verlorenvlei Cottage core. Identifications confirmed by C Griffiths and J Pether. Environmental data are from Day (1969), Kilburn and Tankard (1975) and Kilburn and Rippey (1982). LWS* = Low Water Spring (tide).

The fossil Mollusca are entirely consistent with an interpretation of an essentially *in situ* infauna with epifauna swept in from nearby shorelines. Despite the vigorous coring operation there are a surprising number of whole gastropods and many articulated bivalves. Most of the infaunal taxa are well-preserved, or freshly broken (a function of sampling), suggesting that they are autochthonous. The turritellid gastropod, *Protomella*

capensis occurs throughout the sequence but is particularly common in the deeper mud-clay facies where a number of individuals are preserved in burrows in their living positions. This species is found today on sandbanks in sheltered estuaries such as Knysna Lagoon. Transport paths of the epifauna (eg, the black mussel, *Choromytilus meriodonalis*), appear to have been short-lived. There is no evidence of long-term exposure of these shells at the interface (ie no winnowed lags). Predation is evident from two examples of *Crepidula capenis* with each gastropod bearing a single bored hole. This is in contrast to the findings of Tankard (1975) who could find no evidence of predation on either gastropods or bivalves from assorted late Pleistocene and Holocene fossil deposits at Verlorenvlei. The occurrence of *Psammotellina capensis* indicates that this estuarine bivalve populated Verlorenvlei during the deglacial transgression. This species is today found much further to the east between the Breede and Kei Rivers, beside the Agulhas bank and the warm water of the South Coast.

8.10 The Holocene evolution of Verlorenvlei

'[A]nd the great shroud of the sea rolled on as it rolled five thousand years ago.'

Herman Melville,
Moby Dick

In southern Africa, the West Coast region and Verlorenvlei in particular, has become an important geographical focus for the pursuit of evidence for relative sea-level fluctuations during the late Quaternary (Davies, 1973; Birch, 1976; Tankard, 1975, 1976; Flemming, 1977a-c; Fromme, 1985; Parkington, 1986; Yates *et al.*, 1986; Grindley, *et al.*, 1988; Miller, 1990; Miller *et al.*, 1993; 1995; Jerardino, 1993; 1995). Although much of this research has been driven by the quest to reconstruct the palaeoenvironments of the coastal regions of the southwestern Cape, there is a growing awareness that sea-level research can be used as a critical component in the establishment and verification of a range of ocean-atmosphere models (Stanley, 1995). In view of the vulnerability of low-lying coastal areas to sea-level rise and marine incursion, late Quaternary sea-level reconstructions provide an important indicator of the potential impacts of global warming (French *et al.*, 1985). Palaeoceanographic information of this nature is also useful in resolving the underlying mechanisms of sea-level change and climate, such that future trends can be more readily predicted (refer, for example, to the IGBP Report: Land-Ocean Interactions in the Coastal Zone, No.25).

The Holocene evolution of the Verlorenvlei system, extending from the contemporary mouth to the site of Grootdrift some 15 km inland of the present coastline, can be

inferred from the depositional, erosional and fossil record preserved within the palaeovalley. Figure 8.41 illustrates a comparison of the GSM fraction and mean and sorting curves of the Verlorenvlei Cottage core and the Grootdrift GDN borehole. Despite the differing rates of sediment accumulation at the proximally and distally located sites, the two sets of curves display a remarkable correspondence in their symmetry, suggesting that, for the most part, similar processes were at work at each location. Radiocarbon dates are not available from the lower muddy pulse at Grootdrift but the feature is interpreted as being contemporaneous with the pulse observed from the Verlorenvlei Farm embayment dated to between 8 000 and 7 200 BP. In general, there is good correlation between the GSM fractions and associated mid-Holocene radiocarbon dates from both sites, but frustratingly, no intact molluscs were recorded from GDN.

The variable sedimentology and the divergent mollusc species distributed up the Verlorenvlei Cottage core, indicate that the early to mid-Holocene aquatic status of the Verlorenvlei embayment fluctuated as follows: i) an open estuary; ii) a sheltered lagoon; iii) a terrestrial dune field; iv) an active estuary; v) a marine embayment. With increasing sea-level transgression of the Verlorenvlei River during the deglacial phase (Flandrian transgression) of the early Holocene, *circa* 8 000 BP, the embayment became an extension of a large open estuary where the waters were sheltered and shallow enough to be warmer than modern West Coast estuaries (namely; the Great Berg and Olifants). The thermophyllic mollusc *Psammotellina capensis* is an indication that either warmer sea surface temperatures (SSTs) prevailed during this time period or that climatic conditions along the West Coast were responsible for elevating the water temperature in such sheltered embayments. Cohen *et al.* (1992) have demonstrated that SSTs along the West Coast rose from 10.5 to 13.5° C between 10 000 and 8 000 BP, but the authors are indecisive as to whether the 3° C SST aberration came about in response to an enhanced retroflection of warm Agulhas water into the South Atlantic and Benguela system (Shannon *et al.*, 1990) or whether the inferred temperature anomaly resulted from a decline in the intensity of cold upwelling events off the West Coast, brought about by less intense atmospheric circulation in the southern Benguela region at the time of the terminal Pleistocene. Interestingly, the latter explanation finds some measure of support in the Sandveld pollen data (eg, Elands Bay Cave) which is consistent with an interpretation of warmer temperatures at the time.

By about 8 500 BP sea-levels had transgressed the lower Verlorenvlei valley, contributing to an estuarine environment around the Verlorenvlei Farm embayment. By 7 500 BP, poorly-sorted, dense cohesive 'gley' mud is suggestive of a low energy marine

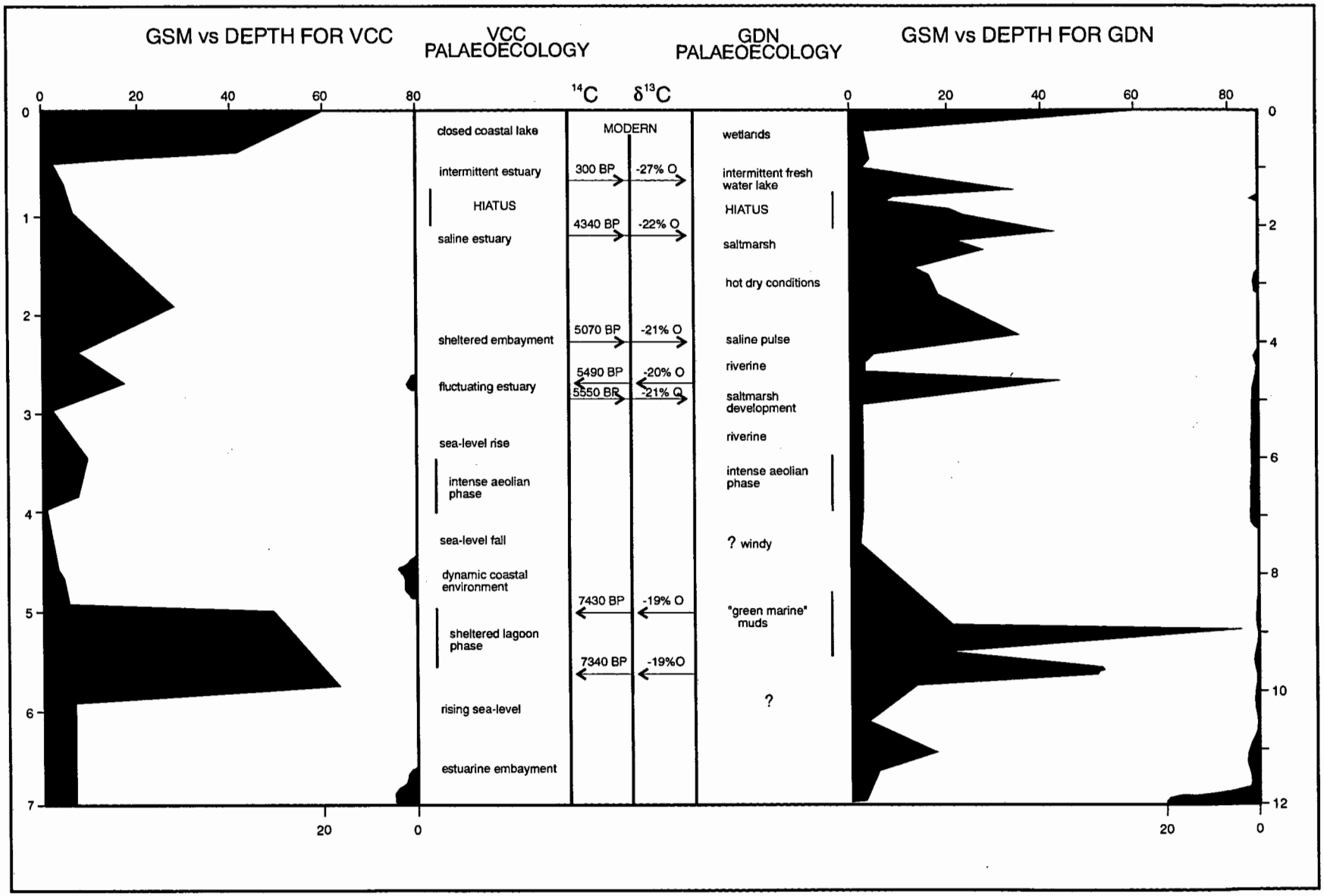


Figure 8.41 Comparison of sedimentology, palaeoecology and chronology from VCC and GDN.

environment with little, if any, post-depositional reworking (eg, winnowing and autosuspension) other than faunal burrowing. Life assemblages of *Protomella capensis* with *in situ* fossils are an indication that, for some time, sea-levels plateaued and the system maintained a sheltered lagoon. The palaeoecology of the infauna suggests that sandy mudbanks were permanently subtidal to a depth of ± 2 m - a situation analogous to sheltered parts of Langebaan Lagoon today. In consideration of the relative height of the cored sediments from VCC, this condition suggests that sea-level had reached a *minimum* height of –2 m amsl along the West Coast by *circa* 8 000 BP and that Verlorenvlei was permanently open to the sea. Following this brief relative sea-level high stand between 8 000 and 7 200 BP, a sudden absence of mud and silt, accompanied by improved sorting of coarser sediments in both VCC and GDN, is suggestive of an isolation contact with conditions reverting back to a more dynamic estuarine-riverine environment, possibly with strong tidal or even wave action in the lower reaches. The fossil Mollusca including *Venerupis, Choromytilus* and the pustular triton, *Argobuccinum*, are consistent with an interpretation of epifauna swept in from nearby rocky shorelines. It is probable that former rocky shores, now buried around the perimeter of Skietkop may have provided an ideal niche for the colonisation of such Mollusca in the throat of the estuary. Evidence from Groenvlei along the southern Cape coast (Martin, 1968), although considerably removed from Verlorenvlei, suggests that sea-levels in this region were in the order of - 3 m amsl by 6 870 BP, and lends some support to the notion of a widespread minor regressionary phase at this time. The return to estuarine conditions at Verlorenvlei appears to have been short and abrupt and probably represents a transitional event as sea-level regressed further and sediments prograded around the mouth. Corresponding samples from GDN fall well within the range of river deposition (Erlank *et al.*, 1992) and indicate a rejuvenation of the Verlorenvlei River at Grootdrift.

Around 6 500 BP, a pronounced change in the sedimentary characteristics, together with the absence of fossil organisms, signals an important shift in the hydrological status and depositional regime at both Grootdrift and the Verlorenvlei Farm embayment. An upwardly fining pulse of 'crusty' light brown sand occurs above 4.60 m, becoming progressively bleached and better sorted (around a mean size of 2 ϕ), by 4.00 m. The lower component is fluvially re-worked and is cemented together by an accession of wind-blown calcareous dust. By 4.00 m the sands are less cohesive, fine-medium, positively skewed and very well-sorted - entirely consistent with the development of subaerial dunes (Friedman, 1961), probably under an intense aeolian regime from the southeast. These sterile white sands are visually consistent with those of the Holocene dunefield to the north of Elands Bay village and reveal abundant biogenic (skeletal) calcium carbonate, suggesting that they too are re-worked from former marine deposits

- probably those left in the wake of the receding sea. Aeolian deposits are a coincident feature of the GDN borehole at Grootdrift. Samples T21 and T22 (Figure 8.41) are texturally and visually indistinguishable from wind re-worked beach deposits (Friedman, 1961) and occur as a ± 1 m pulse above the riverine-estuarine sands. The development of linear source-bordering dunes around Verlorenvlei signals a shift to terrestrial processes at the site and implies a relative sea-level decline in the order of 2 - 3 m, assisted perhaps by the creation of a longshore barrier complex around the mouth of Verlorenvlei as the coast prograded (eg, Grindley, *et al.*, 1988). There is not much reliable dated evidence from elsewhere along the West Coast against which to evaluate this early mid-Holocene sea-level reconstruction, although it does accord with the evidence from sub-tidal reefs in Langebaan Lagoon which suggest that sea-level fluctuated around - 5 m amsl at 6 500 BP (Flemming, 1977a). In addition, Tankard (1976) reports on a sedimentary succession at Saldanha Bay, which bears evidence of a pronounced regressionary event. The undated sequence is believed to be of Flandrian age and reveals an upwardly-fining beach deposit with intertidal fauna. Sediments then become coarser and include fragmented and disarticulated bivalves. This phase is followed by a brief period of pedogenesis resulting in calcrete formation (± 40 cm). This calcrete facies is covered by upwardly fining shelly sand including *Protomella capensis*. Tankard's stratigraphic description is remarkably consistent with that described from VCC and the development of calcrete provides convincing support for a marked early mid-Holocene regressionary event along the West Coast.

There has been much speculation that the mid-Holocene at Verlorenvlei was characterised by unfavourable climatic conditions which, due to the loss of soil moisture and vegetation cover, may have given rise to enhanced wind erosion of the unstable littoral sands (Lancaster, 1986). While the early mid-Holocene fossil pollen evidence from Grootdrift and Klaarfontein is in support of enhanced regional aridity, the sedimentary evidence from both VCC and GDN also points towards a period of active dune formation around Verlorenvlei. In the absence of reliable age-estimates, Miller (1987) has speculated on the development of the extensive Elands Bay dunefield, while Lancaster (1986) has contemplated the initiation of deflation hollows in the Sandveld. It is proposed here, that both these geomorphological features may be the product of the same environmental mechanism which gave rise to the formation of dunes in and along the margins of Verlorenvlei, *circa* 6 500 BP.

Following this brief but intense phase of aeolian deposition, sea-level appears to have advanced rapidly, with estuarine conditions returning to the Verlorenvlei Farm embayment by about 6 000 BP. *Venerupis corrugata* and *Macowa crawfordi* occur

together in the VCC sequence, while corresponding peaks in the mud fraction of GDN and VCC have produced corresponding dates of 5 500 BP respectively, clearly recording the same transgressive sea-level event. A pronounced occurrence of halophytic vegetation at Klaarfontein, coincident with enriched $\delta^{13}C$ values attached to the radiocarbon dates, indicates that the marine influence was impacting as far as 20 km inland of its modern limit. It is expected that enhanced aridity in the Sandveld would have resulted in decreased stream flow in the Verlorenvlei River and a lower discharge rate from the Sandveld springs, thus offering minimal hydrological resistance to the incursion of saltwater up the system. The low sedimentation rate at Grootdrift and Klaarfontein is consistent with reduced sediment transport and depressed fluvial activity during this time. For the next ± 1 000 radiocarbon years, sedimentation demonstrates progressive coarsening in VCC, while GDN reflects upward fining. Mollusca in VCC are comprised exclusively of *Choromytilus* and *Crepidula porcelana*, the former a rocky shore bivalve and the latter a gastropod that burrows in surf beaches. The interpretation for this time period is that sea-levels were fluctuating within one or two metres of their modern extent and that wave action was present in the lower embayment. Periods during which muddy sediments in VCC and GDN are temporarily absent, coincide with a decline in halophytic vegetation at Grootdrift and Klaarfontein, suggesting that two minor negative oscillations may have occurred around 5 200 BP and 4 800 BP, though in general, conditions up the system are consistent with a low energy estuarine-riverine environment. By 4 340 BP, GDN reveals black clay-like sediments which are texturally reminiscent of the earlier lagoonal phase in VCC. Pollen from these levels record a pronounced peak in halophytes and the interpretation is that sea-levels were rising towards the mid-Holocene high stand with saltmarshes becoming fully developed around Grootdrift. Contemporaneous sediments from VCC are dominated by *Protomella* with evidence of burrowing. Unlike the earlier lagoonal phase, these sediments are well-sorted and the particle size is medium-coarse ($< 2\,\phi$), suggesting a high energy depositional environment such as an open marine embayment rather than a sheltered lagoon.

Sometime after the date of 4 340 BP, sedimentation ceases to be recorded in both GDN and VCC - that is, until relatively recently, when the system reverted back to an estuary and finally a coastal lake. As a consequence of this hiatus, little information regarding the sedimentary dynamics or the precise nature of sea-level behaviour is known from this period. Yates *et al.* (1986), Jerardino (1993; 1995), Miller (1990) and Miller *et al.* (1993;1995) have consulted a wide range of proxy archaeological evidence to decipher the sequence of late mid-Holocene sea-level changes in southern Africa and particularly along the West Coast. The overriding conclusion is that a high stand of +3 m

occurred sometime around 4 000 BP and that a substantial regression (at least to its present datum, if not below) took place sometime after 3 500 BP (Jerardino, 1995). Under this scenario, the missing sediments from Verlorenvlei would, in all probability, have been scoured out by a combination of regressing sea-level and fluvial rejuvenation. Based on the absence of continuous sedimentary evidence from VCC and GDN, there is no reason to doubt the interpretation of a mid-Holocene high stand around 4 000 BP. The sediments which do occur between 2.15 and 0.95 m in VCC are characterised by fine to medium brown sands interspersed with shallow clay bands and occasional pockets of coarse sand and shell debris. The sediments have clearly been reworked and offer little conclusive evidence of the depositional environment. However, the dense association of halites in this portion of the core, together with the occurrence of marine ostracods (K Martins, personal communication), points towards a strong marine influence.

Jerardino (1995) has also argued that sea-level regressions during the Holocene might be correlateble to neoglacial expansions, relatively colder SSTs along the West Coast, and moister episodes in the winter rainfall region of the southwestern Cape - an hypothesis which is diametrically opposed to that of Pisias (1978) who has suggested that periods of aridity along coastal California correspond with periods of colder SSTs. To some extent Jerardino's hypothesis can be tested against the fossil pollen record from Muisbosskerm and Spring Cave. The evidence from Klaarfontein and Grootdrift is consistent only insofar as inferred regional aridity corresponds with peaks in halophytic vegetation in Verlorenvlei (a convincing sea-level surrogate), while inferred regional moisture corresponds with fresh water indicators in Verlorenvlei. In view of their geographical location away from the immediate influence of the sea, the evidence from Muisbosskerm and Spring Cave is somewhat more convincing. Both sites signal an increase in regional moisture availability around 2 500 BP - a time which is coincident with depressed sea-levels at Verlorenvlei and slightly colder SSTs (Cohen *et al.*, 1992). Finally, there is a suggestion from the pollen data and sedimentology from Klaarfontein and Grootdrift, that the most recent transgressive event may have occurred around 1 500 BP before sea-levels finally moderated towards their present datum. Prior to the arrival of European colonists, Verlorenvlei was an actively prograding estuary with longshore sand movement contributing to the development of a barrier complex at the coast, forcing the mouth to migrate some distance to the south of the palaeochannel which operated during the mid-Holocene.

8.10.1 A revised Holocene sea-level curve for the West Coast

In summary, the Holocene evolution of Verlorenvlei and the surrounding environments has been strongly influenced by the sequence of relative sea-level rise and fall that has occurred along the West Coast. Four distinct Holocene sea-level phases are recognised from Verlorenvlei (refer to Figure 8.42): An initial transgression around 8 000 BP to within a metre or two of the modern datum; a rapid regressive phase around 6 500 BP during which sea-level fell by at least 3 or 4 m and sand dunes became established along the southern margin of Verlorenvlei; a third, oscillating phase during which sea-levels transgressed towards their maximum extent sometime around 4 000 BP and, finally, a substantial regression following 3 500 BP, probably to below the present datum, followed by a minor recovery at 1 500 BP.

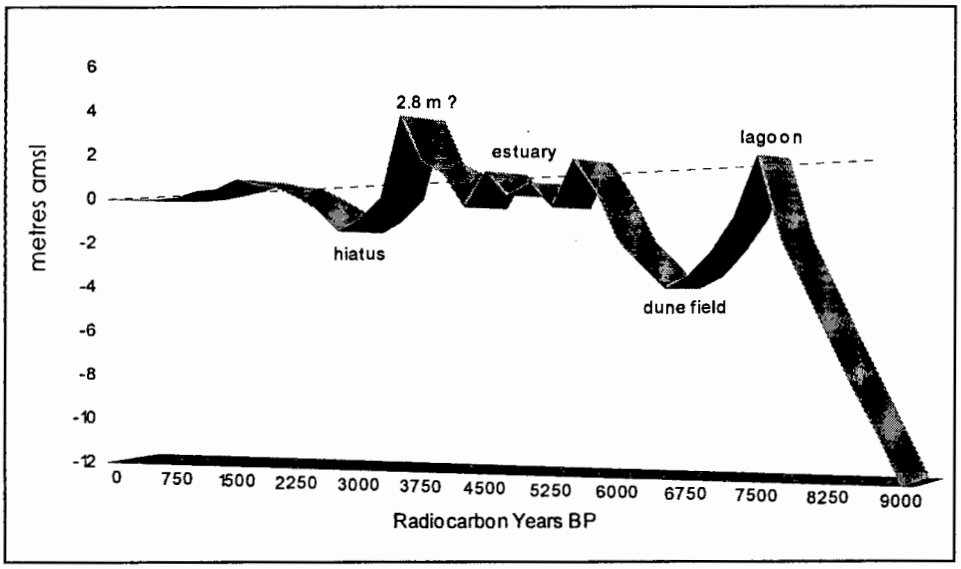


Figure 8.42 The fluctuating status of the Verlorenvlei Farm embayment in response to Holocene sea-level changes. Evidence is based on wide ranging sedimentary, stratigraphic, isotopic, archaeologic and fossil data.

It is unequivocal that these sea-level events have had a profound bearing, not only on the palaeogeography of the West Coast but also on the human-cultural expression within the Verlorenvlei landscape. When viewed against the background of regional Sandveld aridity, punctuated sea-level rise and fluctuating fluvial hydrology, as presented above, the 'anomalous' gap in human occupation at coastally situated archaeological sites, between 8 000 and 4 000 BP, may simply be an expression of the gross inhospitality of the local Verlorenvlei environment. Finally, fossil pollen, fossil mollusc and sedimentological investigations of cores derived from Verlorenvlei have produced

new insights regarding the nature and timing of the West Coast Holocene sea-level history. Interestingly, these new data also demonstrate areas of minor discordance when viewed against the sea-level curves produced by Miller *et al.* (1993) and Jerardino (1995) - refer to Figure 8.43.

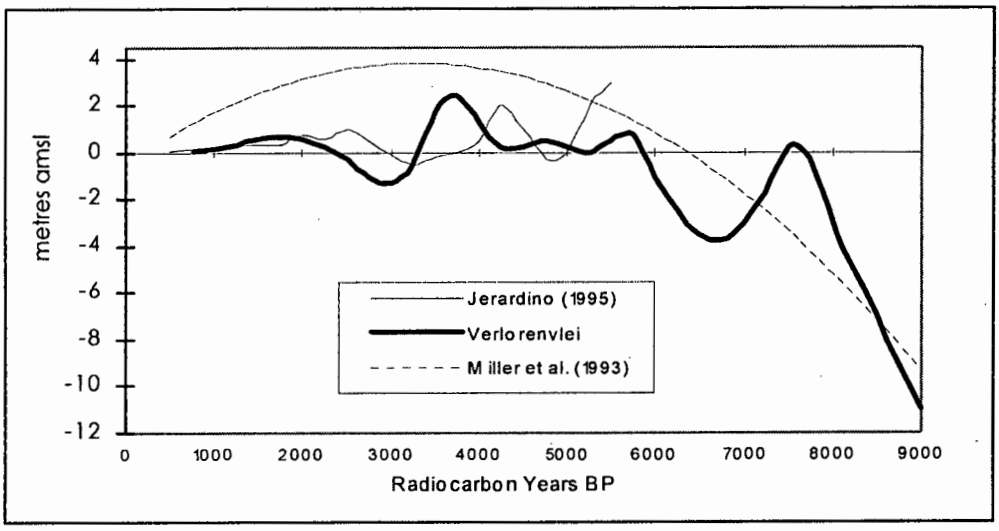


Figure 8.43 The Holocene sea-level curve from Verlorenvlei plotted against the estimated sea-level curves of Miller *et al.* (1993) and Jerardino (1995).

8.11 Conclusions

A wide range of palaeo-information has been presented for consideration in this chapter. Fossil pollen analysis has assumed the principal role in reconstructing the vegetation history for the region since the Last Glacial Maximum and by inference, former climates during this period. Additional insights have been derived from an assessment of the Holocene sedimentology of Verlorenvlei. Textural analysis has revealed a complex history of deposition and erosion, manifested as interdigitating lacustrine, fluvial, estuarine and terrigenous events. Fossil molluscs, preserved in the Verlorenvlei Farm embayment, have aided significantly in reconstructing the estuarine ecology of Verlorenvlei and the Holocene sea-level history of the West Coast. Chapter 9 sets out to synthesise the bulk of this information and to address directly the fundamental research questions as delineated in the introduction of this thesis.

Chapter 9

SYNTHESIS AND CONCLUSIONS

9.1. Some conceptual difficulties and methodological shortcomings

In attempting to synthesise the palaeoenvironmental history of the Sandveld and Verlorenvlei, it is recognised that the physiographical and biological complexity of the region have both assisted and impeded the final interpretation. Consider, for example, that the palaeoenvironmental record from Verlorenvlei is controlled by two primary driving mechanisms: changing climate and changing sediment supply. On the one hand, changes in climate (eg, changes in the frequency and intensity of precipitation) are expected to have controlled the sediment supply from the catchment, and thereby invoke a simple causal relationship. On the other hand, there are a number of changes, unrelated to climate, that have also been controlling sediment supply, viz: increases in erosion due to external changes in vegetation cover (eg, fire and grazing regimes, agricultural clearance etc) and geomorphological changes, such as sedimentation disparities, changes in lake-basin morphometry and sea-level fluctuations - the latter, in particular, adding an extra layer of complexity to the interpretation of environmental change along the West Coast. The palaeoenvironmental puzzle is further complicated by the region's rich phytogeography. For a sub-arid region, the natural vegetation exhibits unusually high levels of diversity, endemism and biomass, and while this has certain advantages in terms of the collection and preservation of fossil plant evidence, it also introduces a number of conceptual and methodological problems relating, in this instance, to the level of taxonomic resolution attached to fossil pollen identifications and the statistical treatment of the multivariate pollen data.

Despite these inherent (and ostensibly unavoidable) complexities, the evaluation and comparison of different forms of palaeoenvironmental data from the Sandveld can offer a reliable means by which to elucidate the nature, timing and magnitude of former environmental changes in the region.

9.2 A synthesis of late Quaternary environmental change in the Sandveld

In support of the fundamental aim of this palaeoenvironmental investigation, a rigorous framework of specific research objectives was outlined in Chapter 1. In attempting to find solutions to these and other research questions, a wide range of

palaeoenvironmental information has been utilised in the quest to unravel and interpret the late Quaternary history of the Sandveld. This collective palaeoenvironmental information has been synthesised into a timetable of environmental events. The data in Table 9.1 are arranged in chronological order and present a succinct account of the important palaeoenvironmental changes (those observable patterns) and some of the underlying climatic and environmental mechanisms (the inferred processes) that have occurred in the Sandveld during the late Quaternary. An annotated summary of the most significant events listed in Table 9.1 is presented in Figure 9.1.

Yrs BP	Climate	T°C	Ppt^n	Sea-level	Verlorenvlei	Regional environs	Local environs	Source(s)
0	Warm / Dry	≈	≈	Mean sl	Coastal lake	Multiple human impacts	Overgrazing & impoundments	Contemp. obs.
350	Warm	≈			Prograding estuary	Diverse fauna & flora	Extensive embayment at GDV	GDV4 / Hist.rec.
1 500	Arid	↑	↓	+1 m	Saline estuary	Xerophytic vegetation	Saline intrusion to KFN	KFN & MBS
2 000	Warm / Dry	≈	≈	Rising	Riverine estuary	Diverse vegetation signal	Freshwater at KFN & MBS	KFN & MBS
2 500	Warm	≈		-1 m ?	Eroding estuary	Mesic fynbos signal ↓SSTs	MBS dune slack established	MBS & SPC
3 000	Cool / Moist	↓	↑	Falling		Increase in fynbos types	Spring rejuvenation at SPC ?	SPC
3 500	Warm / Dry	≈	≈	Falling		Grassy Strandveld	Occupation resumes at EBC	SPC
4 000				+2.8m ?	Mid-Holocene high		Saltmarsh at Grootdrift & KFN	KFN
4 500	Hyper-arid	↑	↓	+1 m		Low terrestrial diversity		KFN
5 000	Hyper-arid		↓	-1 m	Saline estuary	Xerophytic karroid veg.	Karroid influence around GDV	GDV1
5 500				0m	Marine incursion	Low terrestrial diversity	Saltmarsh at Klaarfontein	KFN & VCC
6 000	Hot / Arid	↑	↓	Rising		Xerophytic karroid veg.	Saline indicators at KFN	VCC & KFN
6 500	Windy / Arid	≈	↓	-5 m	Riverine estuary	Active wind deflation	Dunes inundate VCC area	VCC
7 000			≈	Falling		and dune formation	Infratidal molluscs	VCC
7 500		≈		-1 m	Sheltered lagoon	Sea-level plateau	Lagoonal muds & molluscs	VCC
8 000	Hot	↑		-3 m	Saline estuary	Warmer SSTs / EBC hiatus!	Thermophyllic molluscs	VCC
10 500	Warm / Dry	≈	≈	-25 m ?	River floodplain	Grassy Strandveld		EBC
13 000	Cool / Moist	↓	↑	-70 m ?	River valley	Mesic fynbos elements	Rapid sea-level rise	EBC
18 000	Cold / Wet	↓	↑	-110 m	River valley		Rare arboreal pollen taxa	EBC

Table 9.1 Timetable of late Quaternary environmental events for the Verlorenvlei region of the West Coast Sandveld. The symbols ↑, ↓, ≈, propose to indicate *elevated*, *depressed* or *comparable* temperature and precipitation values respectively, relative to the present day situation. Gaps in the data reveal periods for which the environmental history of the region remains uncertain.

The Last Glacial vegetation around Elands Bay Cave appears to have responded to a combination of increased continentality, increased rainfall and reduced temperature. Although detail is lacking, the environment appears to have favoured the development of Mesic Mountain Fynbos and woody taxa (including Afromontane-type trees) around this locality. When compared to the pollen signatures of a range of modern Sandveld vegetation communities, the vegetation-fossil assemblages from this site demonstrate the highest levels of dissimilarity, with NNI values averaging around 0.7 - a convincing

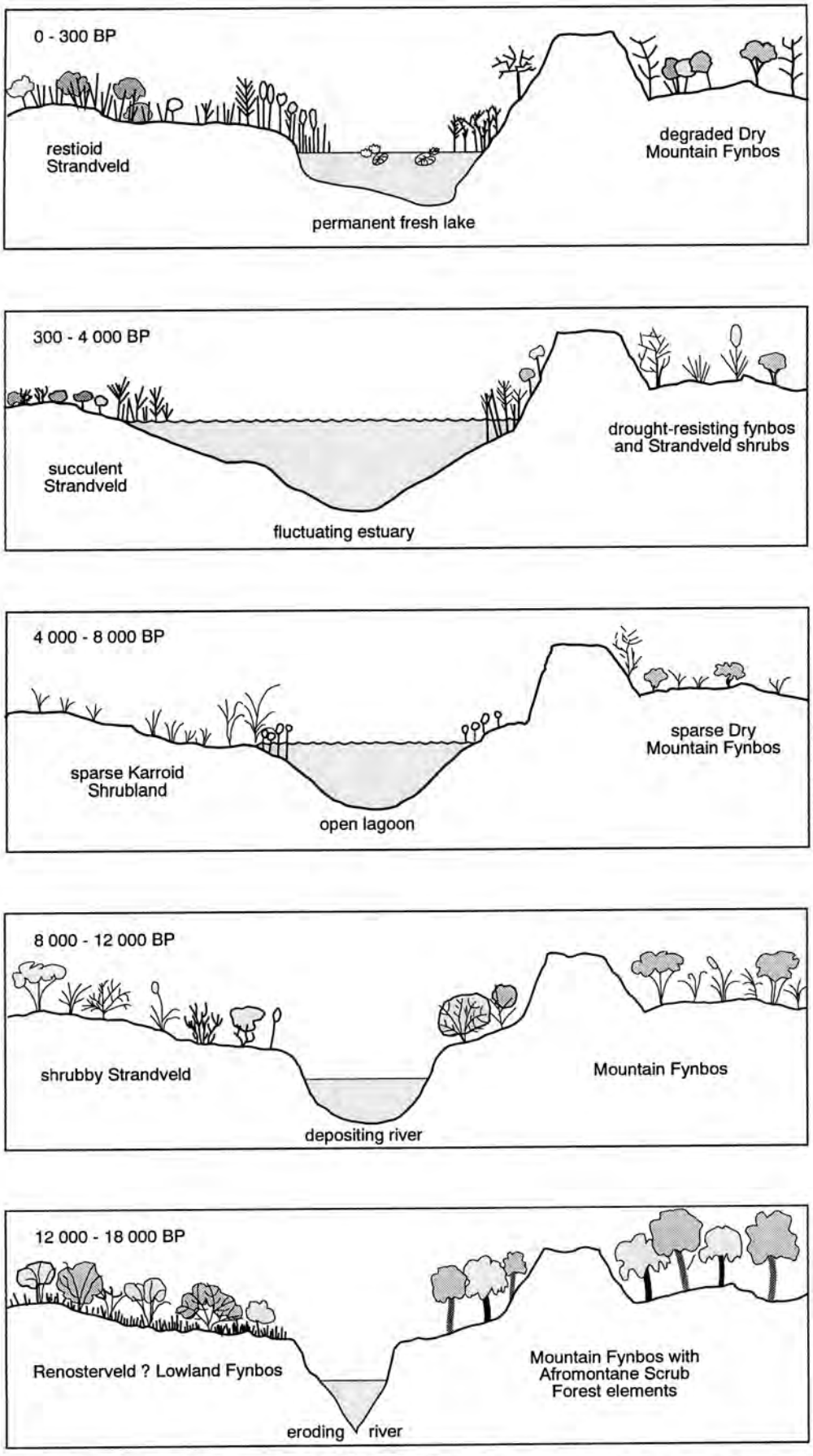


Figure 9.1 An annotated summary of late Quaternary palaeoenvironmental changes at Verlorenvlei.

indication, perhaps, that Last Glacial Maximum vegetation communities have since disassembled in response to significant climatic and environmental change. With the approach of the terminal Pleistocene, rapid sea-level rise, temperature amelioration, and the general expansion and intensification of aridity, appear to have prompted a re-ordering of vegetation community structure. As a result, woodland vegetation, especially climatically sensitive taxa such as various Afromontane Scrub Forest elements, appears to have been substantially reduced and fragmented. Unfortunately the period between 10 500 and 6 800 BP has not yet been resolved in terms of the fossil pollen record and no comment can be made regarding the vegetation history of this time. That this period was climatically and environmentally dynamic is, however, readily apparent in the sedimentology and fossil mollusc record from Verlorenvlei, which reveals a sequence of rapid sea-level rise and bears evidence of hypsithermal conditions and possibly warmer SSTs along the West Coast.

By about 6 500 BP, floristic components appear to have converged and reassembled into communities broadly resembling those within the range of modern Sandveld flora. Certainly, by this time, the modern arid shrublands and grasslands were fully established around the Verlorenvlei catchment. Despite the evidence in support of elevated temperatures and xeric conditions during the early mid-Holocene (6 000 - 4 000 BP), and by contrast, cooler and moister conditions during the late mid-Holocene (4 000 - 2 000 BP), the NNIs reveal that plant-fossil assemblages spanning this period are comparatively similar (60-80%) to the range of modern flora sampled from the region. On this basis, it is tempting to suggest that climatic and environmental changes that occurred during the latter half of the Holocene were not as pronounced as those which occurred towards the terminal Pleistocene and, therefore, relative environmental quiescence has maintained stability among the Holocene vegetation mosaic of the Sandveld. However, it must be stressed that the modern pollen assemblages that have been used in the statistical comparisons were selected from plant communities that are presently juxtaposed to, or straddle, the floristic ecotone at Verlorenvlei and, as a consequence, the NNIs may effectively be concealing the extent to which different vegetation components may have shuffled across the ecotone during the Holocene. That community structure was indeed dynamic among the vegetation is confirmed by referring directly to the pollen diagrams which suggest that the early mid-Holocene was dominated by terrestrial communities with a predominantly karroid affinity (especially succulent and drought resistant shrubs, typical of the xerophytic Karoo and Namaqualand floras) and that the late mid-Holocene was characterised, instead, by greater floristic diversity and a larger proportion of fynbos types (especially Lowland Fynbos typical of more mesic environments). The evidence *does not*, however, lend

support to the notion of wholesale community migration across the ecotone in response to Holocene climatic change. Instead, the most harmonious explanation is a situation in which individual floristic elements waxed and waned across a range of environmental boundaries (climatic, edaphic and hydrologic) in an effort to secure their particular ecological optima.

Owing to the widespread sedimentary discontinuity reflected in many of the Sandveld sites, the vegetation history becomes blurred following 2 000 BP until approximately AD 1650. However, there are indications from Klaarfontein and Spring Cave that minor fluctuations in the relative abundance of various taxa may have occurred in response to burning by Khoi Khoi pastoralists or due to minor climatic perturbations that occurred during the last two millennia. Following the arrival of colonial settlers in the region, the intensification of human disturbances, especially among the terrestrial and riparian vegetation components, is considered to be the primary cause of rapid changes in the sedimentation of Verlorenvlei.

Sea-level appears to have been particularly dynamic during the Holocene and is used to account for the missing sediments observed throughout the Verlorenvlei basin. Transgressive events at 8 000 BP, 5 500 BP and 4 000 BP are believed to have equaled, or in the case of the later date, exceeded the present sea-level. Of considerable interest is the rate at which sea-level appears to have transgressed and regressed during the Holocene. Based on the proposed sea-level curve for Verlorenvlei (Figure 8.42), punctuated bouts of sea-level rise and fall appear to have achieved rates in excess of 50 cm 100 years^{-1}. There is also evidence in support of the notion that regressive phases in sea-level are coincident with depressed SSTs, minor global neoglacial expansions and generally cooler conditions along the West Coast (eg, Jerardino, 1995).

9.3 Towards a revised synthesis for the southwestern Cape

Following the review of recently published and hitherto unpublished palaeo-environmental evidence from the southwestern Cape (outlined in Chapter 2), and in light of the new palaeoenvironmental data presented here from the Sandveld (see also Baxter and Meadows, 1994; Meadows *et al.*, 1994; 1996), it is now deemed possible to proffer a fresh synthesis of the late Quaternary palaeoenvironmental changes in the southwestern Cape. In particular, it is now feasible to reconsider the three fundamental research questions first outlined in the introductory chapter of this thesis, viz:

1. What have been the most important characteristics of the regional climate during the late Quaternary insofar as it has responded to major global changes?

2. Has the region reacted in a spatially and chronologically consistent manner to late Quaternary environmental changes or are sub-regional variations apparent?

3. How will the region respond to climatic changes of the future and, especially, what will the regional response be to assumed global warming?

From the outset it is interesting to note that the characteristics of the Last Glacial Maximum climates of the southwestern Cape are emerging from the Sandveld palaeorecord in contrast to the interpretations of Deacon and Lancaster (1988) and Partridge *et al.* (1990). At least within the true winter-rainfall area of the southwestern Cape region, the evidence points to a Last Glacial Maximum which appears to have been markedly cooler than the present day, (a conclusion which has never actually been in dispute), and characterised by greater moisture availability in the southwest (eg, Elands Bay Cave and the Cederberg). The Holocene is effectively divisible into two, having a first half associated with warmer (hypsithermal) and drier conditions and a second half with temperatures comparable with those of the present day but under conditions in which moisture was apparently more freely available.

	Deacon *et al.* (1983)		Deacon & Lancaster (1988)		Partridge *et al.* (1990)		This thesis	
	Temp	Ppt^n	Temp	Ppt^n	Temp	Ppt^n	Temp	Ppt^n
5 000 to 0 BP	≈	≈	≈	↑	↓/↑	↑	↓/≈	↑/≈
10 000 to 5 000 BP	?	?	↑	↓	↓/↑	↑/↓	↑	↓
Last Glacial Maximum	↓	?	↓	↑/↓	↓	↓	↓	↑

Table 9.2 A revised comparison of late Quaternary palaeoenvironmental interpretations based on published regional syntheses for the southwestern Cape region. The symbols ↑, ↓, ≈, indicate *elevated*, *depressed* or *comparable* temperature and precipitation values respectively, relative to the present day situation. Where ↑ / ↓ or ↓ / ↑ occur, the interpretation suggests; higher followed by lower (and *vice versa*).

In attempting to address the possible reasons for the discordant interpretations (refer to Table 9.2 for a graphic comparison) it is probable that the region has not responded uniformly to the changes of the late Quaternary. Such a conclusion is to be expected, since the southwestern Cape is today characterised by marked regional differences in, for example, the seasonality and quantity of rainfall. There are strong indications that the southern Cape, centered on George (and today experiencing an all-year precipitation regime), has a late Quaternary climatic history rather different from that of the winter-rainfall region proper. This is best illustrated in respect of the Last Glacial Maximum,

which does seem to have been cooler and drier in the southern Cape (eg, Boomplaas) and cooler and moister in the western Cape (eg, Elands Bay Cave and the Cederberg). In this sense, the southern Cape would seem to have responded to late Quaternary precipitation changes in phase with the summer-rainfall interior (see Partridge *et al.*, 1990), while the winter-rainfall southwestern Cape has been synchronously out of phase.

The coincidence of warmer temperatures with drier conditions over the late Quaternary (and *vice versa*) of the winter-rainfall region appears, then, to contrast in respect of moisture by comparison with much of the rest of southern Africa (eg, Partridge *et al.*, 1990). This observation has some interesting implications for the prediction of the climatic response to global warming. If the patterns of the late Quaternary are to be extrapolated, then any increase in mean annual temperature in the winter-rainfall region of the southwestern Cape should be accompanied by a reduction in precipitation and lower moisture availability. By the same deduction, an increase in mean annual temperature is likely to be correlated with an increase in mean sea-level. The lessons of the past should indeed be taken seriously by those involved in land management and planning in the region, for it points increasingly to a rapid rise in sea-level accompanied by acute water shortages (especially in terms of the burgeoning demands of industry, agriculture and urbanisation).

9.4 Recent human impacts at Verlorenvlei: implications for conservation

The high-resolution vegetation history reconstruction gained from the GDV4 pollen spectra has provided a unique and hitherto unprecedented insight into the response of Sandveld vegetation to the subtle, yet pervasive actions of 250 years of anthropogenic disturbance. Although the site at Grootdrift has tended to favour the accumulation of pollen from local wetland and riparian flora, a discernible fynbos signal has allowed for a broader environmental interpretation. The arrival of European settlers in the area *circa* AD 1700 is seen to have initiated a sequence of human disturbances in which changes in herbivory and intensifying agricultural mismanagement have lead to dramatic, possibly irreversible changes in the composition of Sand Plain Lowland Fynbos and sensitive Afromontane Scrub Forest elements.

Palaeolimnological indices suggest that, prior to the arrival of colonial settlers in the Sandveld, the open water embayment at Verlorenvlei was spatially more extensive and hydrologically more variable than today. Palaeohydrological calibration of the fossil pollen data from Grootdrift reveals that permanent marsh-type conditions have

systematically replaced the earlier seasonal lacustrine embayment at the site. Sedimentological evidence derived from the south-bank borehole, GDN, indicates that the mobilisation of exposed surficial sands along the banks of Verlorenvlei, under conditions of both wind and water erosion, was accelerated sometime during the last 250 years. Overgrazing and agricultural clearance in the riparian zone has thus resulted in a progressive infill process or 'throttling' effect around the former embayment. Artificial impoundment of the estuarine lake system during the last century has resulted in seasonal back-flooding of the river with a consequent reduction in stream velocity, contributing to an enhancement of the rate of fluvial sedimentation at the riverine/lacustrine transition at Grootdrift. The contemporary distribution of *Typha* at Grootdrift extends across the entire wetland, thereby restricting the passage of the river. On closer inspection during summer, it becomes apparent that a fluvial delta has developed at the site, with the river dispersing into multiple, sinuous channels, finally disappearing into the muddy alluvial sponge that feeds the lake proper. During winter storms, the impoundments both above and below the estuarine lake system, together with the added restriction of the extensive reed beds themselves, serve to reduce the hydraulic potential of the river and to mitigate against any potential scouring effects. As a result, unprecedented flooding is known to occur seasonally on the farm Grootdrift (P van Zyl, personal communication). It is therefore envisaged that the ecological transformation of the proximal reaches of Verlorenvlei, implicit in the interpretation of the pollen and sedimentary data presented in Chapter 8, is directly attributable to a fundamental change in limnology, consequent upon accelerated rates of soil erosion in the catchment and an alteration in the delicate hydrological regime.

During recent times, the terrestrial Sandveld environs have been heralded for their magnificent profusion of seasonal wild flowers. The local tourist industry has capitalised on the carpets of colourful daisies which are routinely advertised as being both more impressive and more bountiful with the passing of every year. Paradoxically, the increasing abundance of asteraceous annuals in the Sandveld, particularly the spring carpets of *Dimorphotheca, Osteospermum, Ursinia* and *Arctotis* spp., belies the true state of the regional environment (Baxter, 1994; Smuts and Bond, 1995). From the Sandveld pollen data it can be interpreted that the Asteraceae have increased almost three fold in abundance since the onset of agro-pastoralism. Owing to the rapid demise of grasses and other palatable ground cover, it is not difficult to imagine how the tenacious asteraceous shrubs and daisy annuals have been able to proliferate, as pioneer communities, in the wake of vegetation clearance for agricultural purposes and over-grazing of pasturage, thus underlining the anthropogenic changes inflicted upon Verlorenvlei as outlined above.

9.4.1 Conservation and management recommendations for Verlorenvlei

In terms of the criteria for a pristine ecosystem, as outlined in detail in Chapter 4, it must be stressed that the prevailing notion among decision makers that Verlorenvlei continues to function in a state of '*natural ecological equilibrium*' must be revoked. Neither the wetland system nor its catchment area are pristine! In fact, the palaeolimnological and palaeoecological interpretations presented in this thesis suggest, rather, that Verlorenvlei has already reached a '*transitional*' state, as a result of *rapid* ecological changes commensurate with historically identifiable human impacts in and around the immediate catchment. Although many of the aquatic and riparian vegetation changes may be interpreted simply as being successional, the concomitant alterations in the terrestrial flora (and fauna), the ensuing changes in erosion and sedimentation patterns, and the altered physico-chemical limnology, are likely to represent deleterious impacts of far greater long-term consequence than mere successional changes (Davies *et al.*, 1993a,b; Williams, 1988). Even though these impacts might not as yet be readily apparent to the casual observer, it is suggested that without the urgent imposition of an appropriate conservation management strategy, the equilibrium of this unique dryland aquatic ecosystem will soon become irreversibly altered and, coincidentally, the opportunity for meaningful and productive conservation efforts will be seriously compromised.

Local conservators are urged to honour the Ramsar status of Verlorenvlei through the urgent implementation of formal statutory control measures. Surveys of the system should be conducted with a view to zoning the area in terms of conservation priorities, agricultural requirements and wetland uses. In wide consultation with the relevant authorities, landowners, conservators and ecologists, a multiple-use plan should be designed for the area. The effectiveness of such a plan would depend upon direct participation from local communities. Other site-specific recommendations for the conservation and management of Verlorenvlei include:

1. The enforcement of designated zones, and where necessary, the introduction of soil conservation measures and strict irrigation allocations.
2. Where sensitive areas are identified (eg, avifaunal breeding sites, archaeological sites, areas of accelerating erosion due to land mismanagement, etc), compulsory purchase should be initiated and the relevant areas protected.

3. Verlorenvlei should be incorporated within a formal reserve and re-introductions of most of the original mammalian species, including hippopotamus, eland, zebra, hartebeest and smaller antelope should become a priority. This would have a two-fold benefit: the stimulation of regional eco-tourism, and the re-establishment of the natural vegetation mosaic in both the terrestrial and aquatic components of the system. Adjoining livestock farmers would then have the opportunity to invest in game farming for re-sale and hunting, both of which would be more lucrative and beneficial to the region than current pastoral activities.

4. Any reserve should encompass all of the wetland features of the system, together with a considerable part of the catchment. It is essential that, in the last case, local landowners be drawn in and be involved in decision making and management processes.

5. One of the most damaging features of the current situation is the causeway near the mouth of Verlorenvlei. This illegal structure should be removed as a top priority in order to facilitate marine contact and to re-establish normal hydrological regulation within the wetland system.

6. All forms of spray-irrigation agriculture should be discouraged; at present the catchment is showing distinct signs of rapid soil salinisation (personal observation). As the area has already been identified as marginal for irrigation agriculture (Sinclair *et al.*, 1986; Pomuti, 1995), a re-examination of current practices is urgently required and alternative approaches to agriculture and crops are to be encouraged.

Finally, a sustainable management plan for Verlorenvlei could bring to the Sandveld a range of socio-economic benefits in the form of 'eco-tourism' opportunities such as: bird watching, licensed hunting, licensed fishing, canoeing, sailing and 'eco-education' activities such as archaeological, wildlife and diving tours. On the other hand, failure to recognise the deteriorating ecological status of Verlorenvlei would allow the system to decline into a permanently altered state with concomitant losses of biological diversity and life-sustaining ecosystem processes.

9.5 Future research directions

Improved resolution of the fossil pollen record from the Sandveld depends on: i) the development of a more comprehensive reference collection of contemporary pollen (to augment the existing WCP) such that greater taxonomic resolution can be accomplished

during identifications of fossil pollen, and; ii) the implementation of a large scale pollen study of the major vegetation assemblages along the West Coast so that fossil pollen studies can be better placed in the context of modern Sandveld plant communities. This will allow for an improved set of modern analogues and will enhance the reliability of statistical comparisons between modern and fossil data sets.

In line with the general tendency in the southwestern Cape, this investigation of the Verlorenvlei wetlands, despite a concerted search, has not revealed any naturally-occurring, continuous, deep-sequence pollen-bearing deposits dating from the Last Glacial. In retrospect, it seems probable that enhanced fluvial activity in the Verlorenvlei catchment during the terminal Pleistocene, in response to depressed sea-levels and mesic climates, acted in favour of erosional processes, thus mitigating against the development and formation of continuous late Quaternary organogenic deposits. Fortunately, the occurrence of archaeological sites has provided an alternative medium for the preservation of fossil pollen. In the case of the Sandveld, there are a number of deep-sequence deposits that could prove to be useful in enhancing the palaeoenvironmental resolution of the Last Glacial time period. In particular, it is recommended that the excavations at Elands Bay Cave be revisited with the sole purpose of collecting samples for pollen analysis. Careful selection of *in situ* sediments will go a long way towards achieving improved levels of pollen preservation, pollen concentration and pollen identification. In turn, this will allow for the data to be evaluated quantitatively and to be compared with greater objectivity against the detailed charcoal analyses of Cartwright and Parkington (in preparation).

Recent interest in sea-level fluctuations has intensified as a result of the growing awareness of the effects of global climate change. Owing to the universal variations in land motion between continents and coastlines, it is proving difficult if not impossible to create a global sea-level curve for the Holocene (Stanley, 1995). This has put increasing emphasis on the worldwide reconstruction of local sea-level histories. The elucidation of Holocene sea-level change is considered a fundamental objective of the IGBP project on Past Global Changes (PAGES), since these reconstructions will provide a gauge for the projection of changing sea-level positions in the future. The West Coast, by virtue of its inherent tectonic stability, variable coastal morphology and well documented archaeological and palaeoenvironmental record, is well suited to the study of southern African sea-level change, and as a consequence it is proposed that:

1. An extensive vibracoring exercise be initiated in the distal reaches of ephemeral rivers, dune slacks, vleis and estuaries along the West Coast. In particular, longitudinal and cross-sectional core transects should be undertaken in undisturbed reaches of these systems. Potential sites include (refer to Figure 3.2):

    - The Olifants River wetlands inland of Papendorp.
    - The Jakkals River Mouth near Lamberts Bay.
    - Wadrifsoutpan, the culmination of the Langvlei River.
    - The Verlorenvlei Farm embayment.
    - Rocher Pan, the culmination of the Papkuils River.
    - The Berg River estuary.
    - Langebaan Lagoon.

2. Vibracores should be evaluated in terms of their stratigraphy, chronology, sedimentology and fossil content - the latter could include molluscs, ostracods and pollen. The application of fossil pollen analysis, for example, could prove useful in verifying the spatial and temporal occurrence of former saltmarsh vegetation communities, particularly along longitudinal transects extending inland from the coast.

3. A detailed, chronologically-calibrated Holocene sea-level history should be produced for the West Coast. Such a reconstruction could be used to compare sea-level data from elsewhere in southern Africa and would be useful in predicting the rates and magnitude of sea-level rise under various global warming scenarios.

9.6 Conclusion

By way of a final conclusion, the value of palaeoenvironmental science, as a predictive tool for future environmental change, can be summarised by the following pertinent observations from the Sandveld palaeorecord:

1. The mid-Holocene hypsithermal event, a former *natural* warming episode that is widely recognised as having had global significance, can provide a partial analogue for future biogeophysical changes that may be associated with the 'greenhouse effect'. The evidence from the Sandveld suggests that regional aridity can be expected in the southwestern Cape and that fresh water, already in short supply in the region, will increasingly become a critical resource. It is vital that such insights be brought to the attention of those who carry the responsibility of future planning for the region.

2. Without significant human intervention, natural *fynbos* and *Strandveld* vegetation communities are likely to disassemble with differential loss of species as new climatic and environmental circumstances come into effect. The degree to which extinctions will occur is intrinsically dependent on the rate and magnitude of environmental change and the capacity of biotic communities to migrate and reassemble in different geographical areas of the southwestern Cape. In light of the fact that agricultural clearing has resulted in the widespread fragmentation of natural habitat in the region, it is suggested that the capacity for species to migrate or shuffle around the landscape is now severely curtailed (refer to Peters (1988); Bridgewater (1991) and Meadows *et al.* (1993) for discussion on this topic). Accordingly, the implementation of appropriate conservation measures, including corridor-linked reserves which incorporate diverse habitats, is urgently required.

3. The Holocene sea-level history from the West Coast reveals that rapid fluctuations in sea-level are correlated with changes in global temperature. Conservative predictions by the IPCC suggest that a minor increase in thermal warming is presently inducing sea-level rise in the order of 2-4 mm $year^{-1}$. In addition to this rise in isostatic sea-level, human activities in the coastal zone have resulted in the degradation of coastlines at a faster rate than experienced over the last 5 000 years. A combination of mean sea-level rise and burgeoning human impacts around the South African coastline present a serious threat to sensitive coastal ecosystems, particularly those which act as natural barriers to erosion.

4. Finally, the lessons from Verlorenvlei direct that an essential prerequisite of any wetland conservation or management strategy should be the implementation of an appropriate palaeo-investigation - such as the type outlined for GDV4. Such high-resolution reconstructions are extremely useful in defining ecosystem health and measuring after-the-fact environmental variables that are frequently invisible to neoecologists working in restricted temporal domains (refer to Magnuson (1990) and Smol (1992; 1995) for additional discussion on this topic). Retrospective approaches to the evaluation and monitoring of ecosystem health are thus recognised as powerful tools in the formulation of appropriate management plans for the maintenance of ecosystem integrity.

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'The world is not to be put in order, the world is order incarnate. It is for us to put ourselves in unison with this order.'

Henry Miller

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APPENDIX A

Preparation procedure for reference collection pollen

Note: - Source: revised from Sugden (1989).
- Adhere to laboratory safety procedures at all times. Wear protective clothing.
- Centrifuge at 3 000 rpm for 2 minutes, unless otherwise specified.
- Use 20 ml profiled, glass Pyrex tubes in a swing-out configuration centrifuge.
- Always discard chemical supernatants into appropriate waste containers.

1. Place anthers or flower buds into a shallow dissecting dish containing ethanol. Using tweezers and a dissecting needle carefully prize the pollen from the anthers.
2. Remove the flowers and extraneous organic matter from the dissecting dish and then filter the ethanol-pollen suspension through a 180 µm mesh sieve into a glass beaker. Stir vigorously and transfer the suspension to a 20 ml centrifuge tube. Centrifuge and carefully discard the ethanol.
3. Add 10 ml (0.1 M) sodium hydroxide (NaOH) and stir. Place in boiling water bath for 5 minutes, stirring frequently. Centrifuge and decant supernatant.
4. Wash with distilled water, centrifuge and decant.
5. Add 10 ml glacial acetic acid , centrifuge and decant.
6. In a fume cupboard, add 10 ml acetolysis mixture (a solution comprising 90 ml acetic anhydride ($[Ch_3CO]_2O$) and 10 ml concentrated (0.4 M) sulphuric acid (H_2SO_4) mixed in a dry measuring cylinder). Stir vigorously and place in boiling water bath for 3 minutes. Centrifuge and decant.
7. Add 10 ml glacial acetic acid. Centrifuge and decant.
8. Wash twice with distilled water, adding a single drop of aqueous safranine to the second wash. Centrifuge and decant.
9. Wash in a mild solution of phenol to prevent bacteriological and fungal spoilage.
10. Invert the tubes onto blotting paper and allow them to drain.

APPENDIX B

Mounting procedure for reference collection slides

Note: - Source: adapted from Erdtman (1943).

1. Clean and label the microscope slides. Heat paraffin wax until it just melts.
2. Cut tiny cubes of glycerine jelly (preferentially a brand which is phenol impregnated) and using a dissecting needle, wipe the glycerine around the inside of the tube to pick up the pollen residue.
3. Place the glycerine on the centre of the slide and carefully heat the slide on a hotplate until the jelly begins to melt. Caution: do not allow the jelly to boil as the texture of the jelly and the structure of the pollen will be damaged.
4. Using a warm glass rod, place two tiny 'pyramids' of semi-molten paraffin wax on opposite sides of the glycerine jelly.
5. Carefully lower a coverslip onto the two wax mounds to form a bridge, suspended just above the glycerine jelly.
6. Carefully apply heat to the slide until the paraffin wax begins to melt. As this proceeds, the coverslip will slowly descend and the liquid wax will spread out until it envelopes the molten glycerine (the two media are not miscible).
7. Slight pressure applied to the centre of the coverslip will ensure that it to touches both the jelly and the wax - this prevents air bubbles from forming.
8. While allowing the wax to cool and set, invert the slide so that the pollen, suspended in the glycerine jelly, settle on the inside of the cover slip. This ensures that all the grains are in the same focal plane and makes for easier microscopy.
9. Once the wax has set, scrape off any excess that may have extruded from the coverslip.

APPENDIX C

A revised method for obtaining absolute pollen frequencies from clay and mineral-rich sediment samples

Note: - Source: revised from Bates *et al.* (1978); Berglund and Ralska-Jasieswiczowa (1986); Fægri *et al.* (1989); Moore *et al.* (1991) and Horowitz (1992).
- Adhere to laboratory safety procedures at all times. Wear protective clothing.
- Centrifuge at 3 500 rpm for 5 minutes, unless otherwise specified.
- Use 50 ml profiled, sealable, polypropylene tubes in a swing-out centrifuge.
- Always discard chemical supernatants into appropriate waste containers.
- To maintain sanity cultivate patience and develop a strong sense of humour!
- Remember to label all samples clearly.

A Removal of humic acids and clay minerals

1. Place 20 - 50 g of sediment in a glass beaker, add 50 - 100 ml of (0.1 M) sodium hydroxide (NaOH) and stir vigorously. Place the sample in a boiling water bath for 5 minutes and stir.
2. Wash and strain the sample through a 180 µm sieve using (0.1 M) NaOH. Transfer the sample into one (or more) 50 ml polypropylene tubes.
3. Centrifuge and discard the supernatant. If dirty, add more NaOH and repeat. Recombine the sample into a single polypropylene tube as soon as possible.
4. Wash the sample thoroughly in distilled water, stir, centrifuge and decant. Repeat until the supernatant becomes clear. If the presence of clay repeatedly clouds the supernatant or continues to bind the sediment, engage steps 5 & 6.
5. Add 30 ml (0.1 M) sodium pyrophosphate ($Na_4P_2O_7$), stir vigorously and place in a boiling water bath for 20 minutes.
6. Centrifuge and decant the supernatant. Repeat steps 5 & 6 until the supernatant becomes clear.
7. Wash sample thoroughly in distilled water.

B Removal of clastic material

8. Add 20 ml (0.1 M) hydrochloric acid (HCl) and place in a boiling water bath for 20 minutes to remove colloidal silicates and silica-fluorides. Centrifuge and decant.

9. In a fume cupboard, treat the sample with 10 ml concentrated (0.4 - 0.6 M) hydrofluoric acid (HF) and then place the polypropylene centrifuge tubes in a boiling water bath for approximately 3 hours, stirring regularly. Thereafter seal the tubes, centrifuge and decant.

10. Wash the sample thoroughly with (0.1 M) HCl, centrifuge and decant.

11. Wash thoroughly with distilled water, centrifuge and decant.

OR,

8. Add 20 ml (0.1 M) hydrochloric acid (HCl) and place in a boiling water bath for 20 minutes to remove colloidal silicates and silica-fluorides. Centrifuge and decant.

9. Add 20 - 30 ml of a saturated solution of zinc chloride ($ZnCl_2$) (relative density: 1.9), mix thoroughly and leave to stand for 10 minutes to allow the heavier non-polleniferous material to settle out. If clastic material fails to accumulate at the bottom of the tube, gently centrifuge at 800 rpm for 5 minutes.

10. Collect the supernatant in a clean centrifuge tube. This becomes the new sample. Conduct a quick check to see that there is no pollen among the clastic material in the original tube. If there is, then repeat the $ZnCl_2$ treatment; if not, discard the clastics.

11. Dilute the sample with (0.1 M) HCl (which helps to eliminate a white precipitate that may have formed during $ZnCl_2$ treatment) and centrifuge at 3 600 rpm for 5 minutes. Discard the supernatant.

12. Wash with distilled water, centrifuge and decant.

C Acetolysis digestion of extraneous organic detritus

13. Add 10 ml glacial acetic acid, stir, centrifuge and decant.

14. Add 10 ml of the acetolysis mixture - comprising 9 parts acetic anhydride ($[CH_3CO]_2O$) and 1 part concentrated (0.4 M) sulphuric acid (H_2SO_4) - and place the samples in a boiling water bath for 3 minutes. Stir with a dry rod, centrifuge and decant.

15. Add 10 ml glacial acetic acid, centrifuge and decant.

16. Transfer the suspension to a 10 ml glass Pyrex centrifuge tube using distilled water. Centrifuge and decant.

17. Add 9 ml distilled water and 1 ml (0.1 M) sodium hydroxide (NaOH) to obtain a neutral pH. Stir, centrifuge and decant.

18. Wash with distilled water 3 times.

19. For the last wash add 2 drops of aqueous safranine stain. Centrifuge and decant.

20. Add 5 ml warm tert-butanol (TBA), stir, centrifuge and decant.

D Final preparation of samples for absolute counting

21. Use a sterile micropipette to carefully transfer the TBA-pollen suspension from the centrifuge tube to a graduated 10 ml storage vial. Ensure that the last remaining residue in the centrifuge tube and the pipette-tip is transferred by repeatedly flushing with TBA.

22. If there is a large proportion of polleniferous material in the suspension, dilute the concentration by adding TBA until the solution reaches a volume of exactly 8 or 10 ml. If only a tiny amount of pollen is present, centrifuge the vial and carefully extract the sterile TBA at the surface (using a micropipette) until the volume reaches 2 or even 1 ml.

23. Suspend the pollen evenly throughout the TBA solution by subjecting the sealed vial to a high frequency vibrator for 2 minutes.

E Mounting

24. Place a single drop of glycerol (or suitable mountant) on a pre-warmed (45° C) sterile glass microscope slide.

25. When the pollen is evenly suspended in the storage vial, use a micropipette to carefully extract 0.02 ml (or a suitable, precise aliquot) of the TBA-pollen suspension.

26. Carefully release the contents of the pipette, drop by drop, onto the warm glycerol-covered slide. The TBA evaporates quickly leaving the pollen residue suspended in the glycerol mounting medium.

27. Use fresh TBA to flush the pipette. Add the residue to the slide.

28. Place a coverslip over the glycerol suspension and place on a warming table until the mixture has spread to all the edges. Delicate pressure with a dissecting needle can aid this process.

29. Using a micropipette, draw up to 0.5 ml hot, melted glycerine jelly and then apply it, like glue, to the circumference of the coverslip. A steady hand is required to administer the molten jelly in a thin yet consistent line around the edge of the coverslip.

30. Several replica slides should be prepared.

APPENDIX D

Dictionary of ecological significance

IDENT.TAXA	ECODE	TYPICAL CONTENT	ECOLOGICAL SIGNIFICANCE
ACACIA	EXOT	*Acacia cyclops* (A. Cun. G. Don)	Willowy trees. Aggressive invaders of coastal -
		Acacia saligna (Labill.)	dunes/river banks. Introduced from Australia.
AIZOACEAE	KARS	*Aizoon canariense* (L.)	Woody shrub. Nama-Karoo distribution.
		Galenia africana (L.)	Xerophyte. Frequently in disturbed areas.
		Tetragonia spp.	Woody shrub. Nama-Karoo distribution.
AMARYLLIDACAEAE	VELD	*Amaryllis belladonna* (L.)	Common throughout the Sandveld & karroid
		Brunsvigia orientalis (L.)	environments. Generally preferring local damp
		Haemanthus spp.	or shady niches.
APONOGETON	VLEI	*Aponogeton* spp.	'Wateruintjie'. Aquatic. Pools, ditches, marshes.
ANACARDIACEAE	KARS	*Heeria argentea* (Thunb.)	Tree-shrubs of dry, rocky mountain slopes.
		Rhus spp.	Woody shrub. Habitats: Karoo to fynbos.
ASCLEIPIADACEAE	KARS	Family dominated by succulents.	Most have a distinct karroid affinity.
		Cynanchum africanum (R. Br.)	Perennial climber found in shrubby Strandveld.
ASPARAGACEAE	KARS	*Protasparagus* spp.	Spiny shrub on (disturbed) dry rocky sites.
ASPHODELACEAE	KARS	*Aloe* spp.	Succulent. Nama-Karoo & Sandveld distribution.
ASTERACEAE	VELD	Significant Sandveld family.	Well adapted to xerophytic conditions.
		Arctotheca caledula (L.)	Ruderal 'weed'. Disturbed soil & coastal areas.
		Arctotis spp.	Colourful annual herbs, flower in abundance.
		Elytropappus rhinocerotis (L.f.)	Shrub of dry karroid areas and disturbed flats.
		Eriocephalus racemosus (L.)	Shrub of dunes and sandy lower slopes.
		Pteronia onobroides (D.C.)	Aromatic shrub of dry coastal areas.
		Senecio elegans (L.)	Abundant annual on sandy coastal flats.
		Stoebe aethiopica (L.)	Invading Dry Mountain Fynbos due to burning.
BETULA	EXOT	*Betula* spp.	Birch. Exotic. Introduced from Europe.
BRUNIACAEAE	FYNB	*Brunia nodiflora* (L.)	Heath-like shrubs common in moister areas of -
		Berzelia spp.	Lowland and Mountain Fynbos.
CARYOPHYLLACEAE	VELD	*Silene* spp.	Diverse herbs. Found throughout the SW Cape.
CELASTRACEAE	SCRF	*Maytenus acuminata* (L.f.)	Tree of dry-type Afromontane & Coastal Scrub.
		Putterlickia pyracantha (L.)	Spiny rigid shrub of Coastal Scrub & river banks.
		Cassine spp.	Along mountain slopes & streams of SW Cape.
CELTIS	SCRF	*Celtis africana* (Burm. f.)	Deciduous tree. Afromontane & Coastal Forest.

CHENOPODIACEAE	VLEI	*Sarcocornia perennis* (Miller)	Dense, matted associations near tidal marshes.
		Salicornia uniflora (Tolken)	Estuaries, salt-marshes & saline soils of dry rivers.
		Atriplex austroafricana (Aellen)	Saline soils along margins of vleis and rivers.
COLCHICACEAE	VLEI	*Onixotis triquetra* (L.f.)	'Vleiblommetjie'. Marshes, pools and damps.
CRASSULACEAE	KARS	Succulent and herbaceous shrubs.	Xerophytic characteristics. Dry rocky places.
		Cotyledon orbiculata (L.)	Drought-resisting fleshy-leaved shrub. Karroid.
		Crassula capensis (L.)	Tuberous perennial. Rocky slopes, dry areas.
CUCURBITACEAE	KARS	*Citrullus lanatus* (Thunb.)	Tsamma melon. Dry areas of W Cape. Edible.
		Kedrostis spp.	Tuberous perennial. Dry areas of W Cape.
CYPERACEACE	VLEI	Important locally produced element.	Form dense swards during hydrosere evolution.
		Cyperus marginatus (Thunb.)	Perennial sedge preferring fresh water.
		Cyperus fastigiatus (Rottb.)	Dense associations along marshy flats.
		Scirpus maritimus (L.)	Occupies muddy flats near perennial water.
DROSERA	VELD	*Drosera* spp.	Restricted to damp slopes & acid marshes.
EBENACEAE	SCRF	*Diospyros* spp.	Woody tree/shrubs of coastal areas & ravines.
		Euclea spp.	Tree/shrubs of coastal dunes.
ERICACEAE	FYNB	Heaths. Classic fynbos indicator	Mesic montane and lowland habitats.
		Erica spp.	From rocky slopes to sandy flats. Usually moist.
EUCALYPTUS	EXOT	*Eucalyptus* spp.	Assorted introduced Australian 'Gum' trees.
EUPHORBIACEAE	KARS	*Euphorbia* spp.	Mostly succulent. Adapted to xeric conditions.
		Clutia spp.	Common in the Sandveld & Nama-Karoo.
FABACEAE	VELD	Large SW Cape family	Many leguminous plants fix nitrogen to nitrate.
		Aspalathus spp.	Diverse shrubs with a Swartland (shale) affinity.
		Lebeckia spp.	Herbaceous shrubs. Karroid & coastal areas.
		Lessertia spp.	Sprawling shrubs of dry coastal areas & sandy -
		Wiborgia spp.	arid slopes.
FERN SPORES	VLEI	*Pteridium* spp.	Ferns indicate local moisture, seeps & springs.
FICUS	SCRF	*Ficus cordata* (Thunb.)	Deciduous (Fig) tree. Rock clefts and ravines.
GERANIACEAE	FYNB	*Pelargonium* spp.	Herbs & Shrubs. Throughout dry coastal areas.
HERMANNIA	FYNB	*Hermannia* spp.	Small creeping herbs of sandy flats.
HYACINTHACEAE	FYNB	*Lachenalia* spp.	Colourful geophytes prefering damp -
		Ornithogalum spp.	sandy soils.
IRIDACEAE	FYNB	*Antholyza plicata* (L.f.)	Common in dune scrub at Elands Bay.
		Babiana pygmaea (Burm. f.)	Moist sandy areas of Sandveld. In common -
		Moraea fugax (de la Roche)	with other Iridaceae, has edible corms.
		Watonia humilis (Mill.)	Prevalent in semi-marshy conditions.
JUNCUS	VLEI	*Juncus kraussii* (Hochst.)	Saline tolerant rush. Streambanks and vleis.
		Juncus acutus (L.)	Coastal. Prefers permantly damp localities.
KIGGELARIA	SCRF	*Kiggelaria africana* (L.))	Evergreen tree. Forest margins & rocky slopes.

LAMIACEAE	FYNB	*Salvia africana-lutea* (L.)	Aromatic (medicinal) herbs & undershrubs of -
		Stachys spp.	Lowland Fynbos. Frequent near streams.
LIMONIUM	VLEI	*Limonium equisetinum* (Boiss.)	Common in coastal & arid regions, especially -
		Limonium spp.	coastal dunes, estuaries and saltpans.
MESEMBRYANTHEMACEAE		Abundant succulents and shrubs	Widespread from Sandveld to Nama-Karoo.
		Carpobrotus sauerae (Schwant)	Typical spring flower. Popular for its edible fruit.
	KARS	*Lampranthus* spp.	Shrubs & mat-forming succulents of drier areas.
		Ruschia spp.	Woody shrubs with a distinct karroid affinity.
MYRICA	SCRF	*Myrica serrata* (Lam.)	Waxberry tree-shrub. Streambanks and moist -
		Myrica spp.	areas among Lowland Fynbos.
MYRIOPHYLLUM	VLEI	*Myriophyllum spicatum* (L.)	Submerged aquatic (to 2m). Vleis & pools.
NYMPHOIDES	VLEI	*Nymphoides indica* (L.)	Aquatic perennial, indicates permanent pools.
OLEACEAE	SCRF	*Olea capensis* (L.)	Tree of mountain ravines and Coastal Forest.
		Jasminum glaucum (L.f.)	Tree-shrub of rocky hills and riverbanks.
OXALIS	VELD	*Oxalis* spp.	Herbs (sorrels), typical of moist disturbed areas.
PINUS	EXOT	*Pinus pinea* (L)	Tall trees. Widespread 'weeds' introduced -
		Pinus radiata (D. Don)	from the Mediterranean.
PLANTAGO	KARS	*Plantago crassifolia* (Forsskal)	Fleshy perennial. Widespread on coastal sand.
POACAEAE	VELD	Abundant cosmopolitan family	Aridity-adapted. Occur in every environment.
		Chaetobromus schraderi (Stapf)	Among the dunes of the SW Cape coast.
		Cynodon dactylon (L.)	Halide tolerant perennial 'lawn' grass.
		Ehrhata villosa (Schultes f.)	Common along coast of the Nama-Karoo.
		Eragrostis cyperoides (Thunb.)	Perennial favouring arid coastal environs.
		Pentachistas patula (Nees)	Biennial grass on dry sandy lower slopes.
		Phragmites australis (Cav.)	Saline tolerant reed. Fringes deep water areas.
		Sporobolus virginicus (L.)	Halophyte, found especially on saline soils.
PODOCARPUS	SCRF	*Podocarpus elongatus* (Aiton)	Breede River yellowwood tree. South temperate.
POLYGALACEAE	FYNB	*Muraltia* spp.	Rigid shrubs common in Mountain Fynbos.
		Nylandtia spinosa (L.)	Spiny shrub. Sandy areas of SW Cape.
POLYGONACEAE	VELD	*Emex australis* (Steinh.)	'Duiweltjie'. Ruderal weed of disturbed flats.
POTAMOGETON	VLEI	*Potamogeton pectinatus* (L.)	Submerged aquatic in fresh to brackish water.
		Potamogeton pusillus (L..)	Sumberged aquatic prefering fresh water.
PROTEACEAE	FYNB	Significant fynbos indicator	Abundance declines with increasing aridity.
		Leucadendron pubescens (R. Br.)	Tall shrub found on slopes of SW Cape.
		Leucadendron salignum (Berg.)	Attractive fire-resistant shrub. Sandy areas.
		Protea Laurifolia (Thunb.)	Small tree common on acid soil & rocky slopes.
		Serruria fucifolia (Salisb.)	Upright shrub favouring Sandveld mountains.
RESTIONACEAE	FYNB	Significant fynbos indicator	Abound in heath environs & Lowland Fynbos.
		Chondropetalum tectorum (L.f.)	Thatching reed. Confined to SW Cape.
		Willdenowia incurvata (Thunb.)	Sandveld distibution. Form significant, often -
		Leptocarpus impolitus (Kunth.)	dominant, component of Lowland Fynbos.

RHAMNACEAE	FYNB	*Phylica* spp.	Fynbos shrub. Flats & lower slopes in SW Cape.
ROSACEAE	FYNB	*Cliffortia* spp.	Robust shrubs prefering damp fynbos slopes.
		Grielum humifusum (Thunb.)	Small prostrate annuals on dunes & sandy flats.
RUTACEAE	FYNB	*Agathosma* spp.	Aromatic shrub. Rocky slopes & crevices.
		Diosma spp.	Exhibit xerophytic characteristics. Sandy slopes.
SALIX	SCRF	*Salix mucronata* (Thunb.)	Cape willow tree. Streambanks, SW Cape.
SANTALACEAE	SCRF	*Colpoon compressum* (Berg.)	Tree-shrub. Inland or coastal slopes. SW Cape.
		Thesium spp.	Dense shrubs on rock slopes and sandy flats.
SAPINDACEAE	SCRF	*Dodonaea angustifolia* (L.f.)	Tree-shrub. Rocky slopes and shady ravines.
SCROPHULARIACAE	VELD	*Hebenstreitia cordata* (L.)	Herbaceaous shrub of sandy coastal flats.
		Manulea spp.	Small undershrubs and herbs of mountain -
		Nemesia versicolor (E. Meyer)	grasslands and disturbed coastal regions.
		Sutera spp.	Frequent on damp sand flats.
SOLANACEAE	KARS	*Lycium* spp.	Woody, often spinous, shrubs. Distinctly karroid.
		Solanum spp.	Common roadside 'weeds' in drier areas.
THYMELAEACEAE	FYNB	*Passerina* spp.	Robust ericoid shrubs found on sandy flats -
		Lachnaea spp.	and lower mountain slopes.
TYPHA	VLEI	*Typha latifolia* (L.)	Dense stands along stream banks and marshes
ZOSTERA	VLEI	*Zostera capensis* (Stetch.)	Submerged aquatic. Hypersaline & sea water.
ZYGOPHYLLUM	KARS	*Zygophyllum* spp.	Woody shrubs with a largely karroid affinity.

APPENDIX E

Statistical algorithm used in the generation of Euclidian 'distances' or so-called Nearest Neighbour Indices (NNIs)

Note: - Source: Algorithm supplied by Professor L Underhill, Department of Statistical Sciences, University of Cape Town (personal communication).

Let x_{ik} be the pollen count for taxon k in modern sample i, and let y_{jk} be the pollen count for taxon k in historical sample j. Counts should first be converted to profiles:

$$p_{ik} = \frac{x_{ik}}{\sum_{k=1}^{K} x_{ik}} \qquad q_{jk} = \frac{y_{jk}}{\sum_{k=1}^{K} y_{jk}}$$

(K is the total number of taxa identified).

Thus, p_{ik} is the proportion of taxa k in modern sample i, and q_{jk} is the proportion of taxa k in historical sample j. The Euclidian distance d_{ij} between the profiles of modern sample i and historical sample j is then defined as:

$$d_{ij} = \left(\sum (pij - qij)2 \right)^{\frac{1}{2}}$$

For each historical sample j, the Euclidian distance to all modern samples can be computed. These distances are then sorted from smallest to largest; the modern sample i', for example, with the smallest index, is referred to as the 'nearest neighbour' to historical sample j.

Interpretation of the modern nearest neighbours to an historical sample needs to be done with caution, and in the context of all the Nearest Neighbour Indices (NNIs). The collection of all NNIs to historical samples should be inspected and considered carefully. For those historical samples with NNIs which have relatively small values, the conclusion that historical sample j and modern sample i' represent comparable plant

communities is likely to be correct. On the other hand, it does not necessarily follow that historical sample j is an appropriate analogue for modern sample i'. It is possible that historical sample j is unlike all modern samples, and that modern sample i', although it is the nearest neighbour to historical sample j, consists of a different plant community. Thus historical samples, with NNIs which are relatively large, are likely to represent plant communities unlike any of the modern samples.

A useful guideline for deciding that historical sample j is not similar to any modern sample occurs when all the distances d_{ij} to the modern sample are relatively large, and all of similar magnitude. Conversely, a useful guideline for deciding that historical sample j is likely to be similar to the modern sample which is its nearest neighbour occurs when the distances d_{ij} are variable, with both relatively small and large values. It may sometimes be useful and provide further insight to consider not only the nearest neighbour, but also the second and third nearest neighbours as well.

APPENDIX F

Original pollen counts from the Sandveld

1. GROOTDRIFT (GDV1+2) TOTAL POLLEN COUNTS

Depth in cm	5	20	45	65.0	85	105	120	135	150	170	190	205	210	230	235	255	270	280	285	305	330	360	390	435
Radiocarbon years BP								300							4340								5070	
Amaryllidaceae	0	2	0	0	5	11	0	0	0	1	0	0	0	0	0	0	5	0	0	0	0	0	3	0
Aponogeton	2	4	1	6	9	10	9	4	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asteraceae Steebe- type	18	10	9	17	10	3	1	13	5	0	3	0	6	1	0	0	6	3	2	3	0	0	5	1
Asteraceae (echinate)	62	58	47	35	37	38	17	21	53	33	16	9	10	8	17	0	27	4	1	1	11	4	25	9
Broken/obscured	24	54	61	21	42	19	16	45	16	18	23	18	59	50	30	31	42	49	23	49	60	71	34	30
Caryophyllaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0
Celastraceae	0	0	1	5	0	2	0	0	6	1	5	0	0	0	2	0	0	0	2	0	0	0	0	0
Chenopodiaceae	2	2	4	3	7	11	5	8	16	11	0	4	7	5	35	0	19	14	13	19	0	0	3	10
Crassulaceae	2	0	0	0	0	0	0	0	0	0	4	0	9	0	0	0	3	0	7	0	0	8	6	0
Cyperaceae	46	78	59	61	43	21	24	33	5	12	0	3	1	3	1	0	0	0	2	0	0	1	0	0
Drosera	0	2	0	3	0	5	0	0	9	3	5	0	0	0	0	0	2	0	0	0	0	0	0	0
Ebenaceae	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	1
Ericaceae	0	0	0	0	0	0	0	0	3	10	3	0	0	0	0	0	0	0	3	0	0	0	0	0
Euphorbiaceae	6	0	1	1	0	1	0	2	0	0	7	0	4	0	0	3	8	0	0	0	0	0	0	0
Fabaceae	8	4	8	3	6	0	0	0	1	2	9	1	0	0	3	0	1	0	6	0	0	0	0	2
Filicales	114	132	58	35	23	27	64	64	34	15	28	9	8	15	14	12	5	15	8	2	24	33	30	6
Geraniaceae	2	0	0	2	4	0	0	4	8	5	0	0	0	2	2	0	0	0	0	0	0	2	0	0
Hyacinthaceae	2	6	2	5	0	2	0	5	0	2	0	0	0	0	0	0	2	0	0	0	0	0	1	2
Iridaceae	4	0	1	2	9	3	1	6	0	3	0	0	2	1	2	0	0	0	0	3	0	0	0	0
Juncus	2	18	8	7	0	4	0	0	1	0	0	0	0	0	3	0	3	0	0	0	1	6	13	7
Lamiaceae	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	2	0	0	0	0	0	3	0
Mesembryanthemaceae	0	8	2	0	0	2	5	3	0	0	0	2	0	0	8	0	1	0	0	0	6	0	8	0
Myrica	0	0	1	1	0	1	2	0	3	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0
Myriophyllum	0	0	3	0	4	5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nymphoides	0	0	2	5	0	11	9	7	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxalis	2	0	1	8	0	3	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Pinus	4	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae <50um	38	50	17	29	45	23	21	48	23	45	22	31	90	21	60	113	55	88	98	64	35	75	113	60
Poaceae >50um	42	8	24	23	5	0	0	11	6	2	7	7	61	79	23	3	24	3	7	4	0	26	24	5
Podocarpus	0	0	0	0	0	0	2	0	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Polygonaceae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae	0	0	1	0	1	3	0	3	6	4	9	2	0	2	2	0	0	0	2	3	0	0	0	0
Restionaceae	2	4	1	5	12	6	13	12	5	3	13	0	12	11	1	12	11	7	5	15	4	7	5	11
Rutaceae	2	0	1	0	0	0	0	2	5	5	4	0	0	0	3	0	0	0	0	0	0	0	0	0
Santalaceae	2	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapindaceae	0	0	0	0	0	0	0	0	2	2	3	0	0	0	0	0	1	0	0	0	0	0	0	2
Scrophulariaceae	8	4	6	1	11	5	0	3	0	3	5	0	0	0	0	0	0	0	2	0	0	3	0	0
Solanaceae	2	0	0	0	0	0	0	0	2	0	6	0	0	0	0	0	3	0	0	0	0	0	0	0
Thymelaeaceae	0	0	3	2	2	0	0	0	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Typha	14	10	3	8	1	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	6
Unidentified	6	6	7	3	6	11	12	10	15	6	14	4	7	10	15	9	34	20	21	8	17	26	18	7
Pollen counts	416	464	334	285	282	230	201	308	250	189	203	92	278	208	223	183	254	202	205	175	163	263	292	159
Pollen grains g^{-1}	46154	13152	11642	8943	13007	14150	20020	29621	38612	21022	14514	11525	23576	16667	26524	13020	21599	17329	19449	15934	11027	22196	34272	18655
Pollen grains cm^{-3}	30769	8827	7660	5923	8502	9129	13527	20014	26447	14109	9425	7248	15017	10965	23266	8797	14304	11709	13892	12124	5459	11210	24656	13443
Sed. acc. rate (cm yr^{-1} x 10^2)	47	47	47	47	47	47	47	47	*	5	E	D	I	*	23	23	23	23	23	23	23	23	23	11
Poll. acc. rate (grains cm^{-2} y^{-1}	14462	4149	3600	2784	3996	4291	6358	9407	H	I	A	T	U	S	5351	2023	3290	2693	3195	2789	1256	2578	5671	1479

2. GROOTDRIFT (GDV4) TOTAL POLLEN COUNTS

Depth in cm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	115	120
Radiocarbon years AD															1747					1640				
Alzoaceae	11	4	3	12	3	10	6	4	7	4	2	3	7	5	0	0	0	3	0	0	0	0	0	10
Amaryllidaceae	3	6	12	21	12	3	14	6	3	6	7	0	6	3	2	0	0	14	0	0	0	6	0	0
Anacardiaceae	0	0	0	5	4	0	0	5	0	2	3	1	0	6	0	6	3	3	0	0	0	0	0	25
Aponogeton	0	4	0	10	7	0	11	13	9	9	0	6	13	12	14	16	9	17	0	13	15	29	40	61
Asclepiadaceae	3	6	3	13	0	9	0	0	0	1	4	0	0	0	0	2	0	0	0	0	6	1	1	0
Asparagaceae	18	8	12	7	3	0	0	0	3	0	0	9	0	0	0	0	1	0	3	0	0	0	0	0
Asteraceae undiff.	184	167	95	129	49	66	93	91	121	115	75	89	55	46	25	32	31	64	46	49	54	32	54	31
Betula	3	5	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broken/Obscured	19	35	24	18	23	30	18	30	19	25	29	12	26	9	21	18	27	9	14	14	12	9	30	41
Caryophyllaceae	0	0	0	7	0	0	0	0	6	6	3	0	0	0	0	0	2	5	3	0	5	0	3	15
Celastraceae	9	12	12	6	3	6	3	15	6	10	7	13	15	15	12	16	12	17	10	9	0	11	13	17
Chenopodiaceae	3	0	0	0	0	6	10	4	10	3	6	3	0	6	4	6	3	6	3	8	6	10	24	20
Colchicaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	6	11	5	15
Crassulaceae	12	6	0	0	3	6	7	0	6	3	9	10	3	7	0	2	3	7	2	7	10	0	10	5
Cyperaceae	31	51	44	46	35	81	81	33	48	65	34	19	9	27	15	17	18	23	21	22	19	6	15	29
Ebenaceae	7	3	1	3	0	0	0	0	12	0	0	0	2	0	0	0	0	3	0	0	0	0	3	0
Ericaceae	0	0	0	0	0	0	6	0	6	7	0	2	3	0	0	0	0	18	3	0	0	0	0	0
Euphorbiaceae	25	20	10	4	11	13	6	0	14	11	7	10	8	2	1	4	7	16	13	9	11	3	0	18
Fabaceae	24	14	13	15	7	11	10	2	0	10	3	1	6	5	6	4	9	3	0	5	3	0	9	7
Filicales	33	14	18	45	19	33	45	21	18	9	44	27	29	15	26	36	23	33	16	20	25	32	13	34
Geraniaceae	0	0	0	6	3	5	14	0	0	9	3	0	0	0	0	3	0	0	0	0	0	0	0	0
Hyacinthaceae	12	16	18	14	4	15	27	15	9	30	34	19	36	11	21	18	27	19	20	14	12	9	30	41
Iridaceae	6	3	6	21	0	10	6	3	2	0	5	7	3	2	0	0	0	10	2	0	0	2	6	15
Juncus	25	35	21	55	16	38	36	9	6	33	25	38	9	18	15	15	9	21	6	3	10	0	10	13
Mesembryanthemaceae	13	3	3	9	0	0	0	6	1	0	12	5	0	3	0	0	7	0	0	0	0	0	3	0
Myrica	12	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myriophyllum	0	0	0	0	0	0	0	0	0	0	0	6	2	4	3	9	9	18	12	12	9	12	18	42
Nymphoides	0	0	0	0	0	0	0	10	13	0	7	0	13	20	30	34	31	84	67	40	52	27	39	29
Olea	0	6	0	6	3	2	5	2	3	0	6	6	12	10	2	3	0	15	9	1	13	2	18	5
Oxalis	19	20	12	7	3	4	0	0	27	0	0	1	0	0	0	0	0	2	1	0	0	0	3	0
Pinus	6	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae undiff.	43	72	59	117	57	138	87	103	97	90	81	108	93	96	77	71	109	137	106	117	141	87	144	187
Podocarpus	0	0	0	0	0	6	5	10	6	14	5	5	6	7	9	3	2	10	5	1	12	0	6	3
Polygonaceae	0	0	0	3	3	4	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potamogeton	0	0	0	0	0	0	0	0	0	8	15	16	17	7	13	18	14	29	25	13	12	6	10	8
Proteaceae	0	3	0	0	9	12	13	17	14	15	16	15	9	6	7	3	4	16	7	3	3	0	9	13
Restionaceae	12	10	4	10	10	23	37	29	15	39	16	20	28	18	6	12	16	24	25	6	28	18	25	37
Rosaceae	5	6	6	3	0	3	0	0	0	0	0	6	0	5	0	0	0	3	2	0	1	0	6	0
Rutaceae	8	6	3	6	12	4	3	4	4	7	12	3	8	3	4	0	2	5	4	0	3	3	9	0
Santalaceae	0	0	0	0	0	0	0	0	0	3	15	0	3	0	10	6	0	6	0	0	0	0	0	0
Sapindaceae	6	0	0	0	0	0	0	9	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scrophulariaceae	36	39	28	25	11	16	15	15	25	15	6	6	6	10	3	3	6	6	7	10	3	7	0	3
Solanaceae	10	9	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Thymelaeaceae	9	12	7	13	2	15	13	10	0	23	3	15	3	10	2	2	3	15	6	0	6	7	10	0
Typha	64	43	31	36	22	17	22	16	19	22	9	12	3	9	3	8	4	9	0	0	10	3	6	12
Unidentified	17	28	16	32	21	9	31	23	21	39	18	10	30	33	21	29	21	21	36	27	30	26	28	39
Pollen counts	671	648	466	678	335	586	593	482	535	597	503	493	433	397	331	367	391	670	442	377	487	333	572	746
Pollen grains g^{-1}	80649	66122	53604	70332	20603	24056	39376	38073	36395	22111	23952	21068	24463	21207	17513	26140	11083	25495	28010	16194	13711	12500	17903	29186
Pollen grains cm^{-3}	53766	44377	35266	45375	13466	15520	26605	25725	24928	14840	15553	13251	15582	13952	15362	17662	7340	17226	20007	13060	6787	6313	12880	20997
Sed. acc. rate (cm yr^{-1} x 10^{-2})	34	34	34	34	34	34	34	34	34	34	34	34	34	34	17	17	17	17	17	17	17	17	17	17
Poll. acc. rate (grains cm^{-2} $year^{-1}$)	18280	15088	11990	15428	4578	5277	9046	8746	8475	5045	5288	4505	5298	4744	2612	3003	1248	2928	3401	2220	1154	1073	2190	3570

Depth in cm	10	20	26	34	42	47	55	65	75	84	95	105	118	128	133	140	150	160	173	179	187	200	210	225	245	262	285	300	322	350	376	400	424	450	475	495	512
Radiocarbon years BP				170								1900										3640															6870
Acacia	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aizoaceae	4	13	17	8	14	2	5	13	17	5	8	9	4	7	6	0	12	11	7	5	13	7	5	3	7	3	1	2	0	2	0	1	2	0	0	3	4
Amaryllidaceae	2	3	2	1	0	2	0	0	0	0	0	0	0	2	0	4	3	4	6	3	1	1	0	0	0	3	3	2	0	2	0	0	1	2	0	1	3
Anacardiaceae	15	7	0	4	6	10	3	6	6	0	0	7	0	7	8	4	7	6	0	7	5	5	5	2	3	0	2	3	0	0	2	0	2	3	1	3	7
Aponogeton	9	4	2	6	0	0	0	2	0	0	0	5	3	0	7	1	9	5	6	4	5	0	3	0	0	0	2	0	3	0	0	0	2	0	2	3	4
Asclepiadaceae	7	8	8	6	0	0	0	4	0	0	0	0	0	0	0	0	0	0	3	9	7	5	0	4	7	3	2	0	2	2	0	2	0	3	2	0	3
Asphodelaceae	13	8	4	4	1	4	0	0	1	0	2	0	0	0	0	0	0	4	0	8	5	6	8	7	0	7	1	2	1	4	3	7	0	0	1	0	2
Asteraceae Stoebe -typ	33	14	3	16	27	10	32	33	13	25	14	10	0	8	4	12	32	45	29	57	49	50	67	23	12	7	12	3	4	7	11	18	15	5	6	12	11
Asteraceae (echinate)	223	117	167	87	73	58	46	39	43	29	51	64	78	43	72	71	35	33	40	38	47	69	34	42	45	22	56	39	25	21	33	17	18	39	30	69	72
Broken/obscured	10	12	15	15	17	14	20	6	22	39	10	27	16	24	17	7	27	27	9	7	7	12	9	22	11	7	12	12	7	30	13	7	6	33	12	21	8
Celastraceae	13	8	7	8	7	0	0	3	4	3	4	7	2	3	4	3	9	13	16	5	6	1	4	5	2	3	3	0	3	0	0	6	4	2	3	4	8
Chenopodiaceae	3	0	0	5	14	17	27	18	9	6	5	0	3	0	0	7	17	21	36	40	57	88	66	56	29	46	13	26	16	5	43	77	32	6	11	8	13
Crassulaceae	13	16	10	5	14	15	12	13	5	8	9	14	6	11	4	7	0	4	3	2	5	2	0	0	4	3	0	0	0	0	0	0	4	0	3	8	7
Cyperaceae	76	45	67	137	113	74	63	56	16	16	19	33	41	31	71	55	105	73	22	20	8	4	14	6	23	9	27	11	7	3	5	13	5	5	11	13	14
Drosera	11	7	7	4	0	2	4	0	1	6	4	0	7	2	6	21	21	3	13	4	0	0	2	0	7	1	4	3	12	0	3	0	3	0	5	5	6
Ebenaceae	8	11	5	13	7	3	2	11	0	0	4	3	0	0	0	0	0	3	11	6	6	15	3	6	11	6	22	9	5	0	0	0	1	4	0	5	4
Ericaceae	0	0	0	0	3	3	4	2	0	0	0	0	0	4	2	5	7	0	0	0	1	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	14	23	7	12	9	11	2	6	6	0	11	13	4	14	4	10	17	13	31	16	22	8	5	11	3	6	7	9	3	2	5	3	3	0	3	6	5
Fabaceae	21	12	8	6	8	20	13	8	13	11	2	17	13	5	4	17	4	3	21	26	31	32	17	17	16	8	21	12	7	9	1	7	6	2	2	6	11
Filicales	24	40	24	23	3	9	8	6	3	13	7	12	23	3	12	21	11	8	3	13	21	19	9	23	7	15	11	12	11	8	24	21	19	5	31	33	12
Geraniaceae	1	0	0	0	0	0	5	0	0	0	0	0	0	4	8	6	25	12	0	0	0	2	0	0	0	0	2	6	0	0	0	0	1	0	0	2	1
Hermannia	8	13	7	11	6	7	12	9	4	7	1	3	0	3	1	1	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0
Hyacinthaceae	4	7	4	1	0	0	3	2	0	0	0	0	3	0	0	8	3	6	1	2	1	1	1	0	2	2	5	1	1	0	3	2	1	3	0	1	2
Iridaceae	6	8	3	5	1	0	3	2	5	0	4	3	3	12	0	0	7	3	2	2	1	1	2	0	3	3	4	3	1	0	0	2	7	1	2	2	3
Juncus	15	21	13	5	2	3	6	7	12	83	67	59	35	13	12	10	22	5	0	4	0	8	2	11	0	3	15	8	0	2	0	5	2	3	0	5	1
Limonium	0	0	0	0	0	5	1	2	0	0	0	2	0	3	0	0	7	0	0	0	6	13	10	14	6	0	2	0	0	7	0	17	1	8	4	5	0
Mesembryanthemacea	23	21	13	7	19	10	14	9	6	7	11	12	7	8	7	17	14	12	16	19	25	20	9	8	7	10	6	7	8	6	1	4	8	1	6	2	3
Myrica	0	2	0	4	0	5	2	0	3	0	2	0	0	5	12	1	2	0	0	0	0	1	0	0	0	0	2	0	1	0	0	0	0	0	1	2	3
Myriophyllum	0	0	0	0	0	2	3	5	0	0	0	0	11	0	0	0	8	0	2	0	4	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Olea	0	0	0	0	0	0	7	2	0	0	0	0	0	0	8	2	5	3	0	0	3	0	7	0	3	1	0	0	1	0	2	0	2	1	0	0	4
Oxalis	44	15	5	12	3	7	9	2	4	0	0	3	0	0	7	3	6	1	4	5	4	0	6	0	3	4	3	5	1	0	2	0	1	2	3	4	5
Pinus	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae <50um	28	37	71	37	25	59	71	55	59	86	109	91	143	74	61	87	79	45	43	80	86	140	114	159	119	137	170	155	101	137	69	99	65	134	90	155	132
Poaceae >50um	21	8	11	9	3	10	35	21	15	30	13	15	15	7	8	20	42	67	46	91	90	94	132	33	31	14	20	12	6	28	25	55	39	16	14	37	45
Podocarpus	1	0	0	0	5	2	4	2	0	0	0	0	0	5	3	4	2	2	0	0	0	0	1	0	2	1	1	0	0	0	1	0	0	0	2	3	0
Polygalaceae	0	0	0	0	0	0	2	3	0	0	0	0	1	5	6	8	3	0	1	0	0	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	2
Proteaceae	3	4	5	3	2	2	14	2	0	0	9	4	3	2	0	2	1	1	3	5	1	0	5	0	3	2	0	1	0	1	3	0	1	0	0	1	2
Pteridium (cf.)	13	13	20	6	11	0	3	0	0	0	5	4	0	3	0	5	26	17	4	11	8	0	0	2	0	0	4	0	0	0	3	0	0	0	5	14	8
Restionaceae	12	10	16	3	34	27	49	29	7	9	25	11	11	25	28	3	0	6	5	8	10	5	6	13	23	7	5	13	6	4	6	11	5	9	5	13	15
Rosaceae	3	3	2	0	0	4	13	5	3	3	0	5	7	1	8	3	9	5	6	8	3	0	14	0	5	5	2	2	0	0	0	1	1	0	0	2	5
Rutaceae	0	0	3	0	0	0	12	3	2	0	0	0	5	1	4	5	4	5	0	2	1	0	1	0	1	3	0	0	3	0	0	1	0	0	0	0	2
Santalaceae	11	6	2	5	5	0	3	0	0	0	0	0	4	13	11	3	2	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	2
Sapindaceae	0	0	0	0	2	0	0	4	0	0	0	0	4	0	0	0	2	0	0	0	0	0	3	0	0	0	2	0	1	0	3	0	0	0	0	3	3
Scrophulariaceae	38	27	25	17	23	8	12	11	6	4	3	5	13	12	4	13	2	8	6	15	7	11	6	0	0	2	10	7	2	10	5	9	2	1	7	8	4
Solanaceae	3	4	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	6	0	15	3	0	3	4	5	2	0	1	0	0	3	0
Thymelaeaceae	0	0	0	0	0	9	9	3	0	0	0	9	0	0	9	5	7	11	2	1	3	0	0	0	4	1	1	3	4	0	3	0	2	0	2	0	3
Typha	54	29	15	19	11	6	4	2	0	0	3	0	0	9	10	12	37	54	13	20	0	0	2	0	0	0	3	0	0	0	0	0	0	3	0	8	5
Unidentified	5	18	13	13	16	23	17	12	9	7	17	7	16	11	20	8	23	7	11	7	7	16	6	36	7	10	0	5	11	22	10	22	9	13	22	12	10
Zygophyllum	5	5	13	14	4	8	5	0	1	0	0	4	3	5	0	5	4	11	7	3	8	13	11	12	7	6	2	3	7	1	9	2	3	2	5	1	8
*Charcoal presence		*							*	**	*														**												
Total organic carbon %	4.9	5.4	2.6	2.9	3.0	1.1	5.3	2.4	4.4	1.8	0.6	3.1	4.1	6.7	14.9	2.1	5.2	1.4	5.8	5.6	8.1	4.9	10.1	6.6	2.2	3.1	7.7	4.3	4.1	1.8	3.3	2.6	4.2	3.3	2.9	10.2	7.2
Pollen counts	780	603	598	531	490	451	559	418	295	397	419	458	484	385	448	468	661	562	433	552	567	656	599	515	430	365	458	383	265	318	291	409	274	306	291	485	462
Pollen grains g^{-1}	39063	32385	29908	35924	18081	11108	37118	24763	15051	17644	14964	22019	16407	34277	44444	31250	46840	26731	37418	24986	29930	27703	33479	26281	17339	11699	14679	17263	11950	14340	11429	16064	10942	12864	11248	18746	16104
Pollen grains cm^{-3}	24881	20627	19050	20765	10636	7661	22226	14566	9013	10379	9717	13849	10450	19929	38986	19531	27392	18062	26727	17847	18590	17207	24085	18907	11044	7799	9786	11508	8536	10243	8164	11474	7929	9321	8034	13390	14379
Sed. acc. rate (cm yr^{-1} x	18	18	18	18	*	*	*	S	E	D	I	M	E	N	T	A	R	Y	*	*	*	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Poll. acc. rate (gr. cm^{-2} y	4479	3713	3429	3738	*	*	*	*	*	H	I	A	T	U	S	*	*	*	*	*	*	1721	2409	1891	1104	780	979	1151	854	1024	816	1147	793	932	803	1339	1438

4. MUISBOSSKERM (MBS) TOTAL POLLEN COUNTS

Depth in cm	15	31	47	55	60	70	80	90	105	115	120	130	140	145	150	188
Radiocarbon years BP													2200			
Acacia	6	6	17	8	1	0	3	0	0	0	0	0	0	0	0	0
Aizoaceae	15	11	23	25	6	0	12	0	0	48	27	15	8	21	12	21
Amaryllidaceae	0	2	3	0	0	1	0	0	0	3	5	0	0	2	1	0
Anacardiaceae	22	9	14	7	5	25	14	19	8	26	29	22	17	32	25	28
Asclepiadaceae	2	19	6	3	0	0	17	0	6	8	0	0	0	3	0	0
Asphodelaceae	0	0	7	1	0	0	0	0	0	0	4	0	0	2	0	0
Asteraceae *Stoebe* -type	6	29	13	68	75	35	30	29	25	7	12	17	16	27	16	24
Asteraceae (echinate)	98	137	87	77	41	31	59	111	97	81	32	30	16	17	19	37
Broken/obscured	12	8	22	8	13	20	24	19	10	7	11	30	8	21	30	22
Caryophyllaceae	14	0	2	0	5	0	0	0	0	5	12	3	0	0	0	0
Celastraceae	19	20	31	28	44	17	9	6	3	29	18	20	17	27	12	15
Chenopodiaceae	3	23	7	11	5	10	28	14	34	2	23	24	15	12	24	10
Crassulaceae	31	37	21	17	11	28	43	32	45	16	14	4	5	9	8	12
Cucurbitaceae	7	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	0	0	0	0	5	14	8	11	1	21	27	52	29	61	31	16
Ebenaceae	25	23	8	15	7	43	14	8	12	16	65	54	17	36	21	0
Euphorbiaceae	12	6	16	7	0	2	18	52	9	5	10	5	11	12	8	0
Fabaceae	15	41	12	5	14	1	3	5	18	24	13	8	13	38	15	11
Filicates	18	49	8	12	66	178	43	327	167	122	43	29	34	29	37	0
Geraniaceae	3	0	2	0	0	0	0	0	0	0	2	0	0	7	4	2
Hyacinthaceae	0	1	0	0	0	0	2	0	1	0	5	12	2	8	3	0
Iridaceae	0	0	1	0	0	7	0	3	6	0	2	0	3	0	0	4
Juncus	0	0	0	0	1	0	8	4	16	13	43	31	42	29	10	0
Lamiaceae	0	0	3	0	8	0	6	0	0	24	9	13	7	14	6	19
Limonium	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesembryanthemaceae	18	25	15	7	16	19	37	45	23	13	8	12	10	8	1	33
Myrica	0	0	5	0	0	0	0	0	0	0	0	2	0	7	11	2
Nymphoides	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0
Oxalis	3	0	1	0	0	0	0	1	0	7	0	0	0	8	0	9
Pinus	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Poaceae <50um	30	8	13	17	62	101	113	57	38	103	128	137	80	127	67	118
Poaceae >50um	21	35	54	44	40	61	21	22	11	23	13	31	11	26	15	10
Podocarpus	0	0	0	0	0	0	0	0	0	0	3	3	0	0	1	0
Polygalaceae	0	4	0	20	0	0	0	0	0	3	0	0	0	0	0	0
Proteaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	1
Restionaceae	13	5	15	3	0	49	13	0	13	19	30	37	29	45	17	18
Rosaceae	0	0	0	0	0	0	0	0	0	7	0	0	0	5	12	0
Santalaceae	0	2	0	0	0	0	6	0	0	13	15	10	0	0	3	11
Sapindaceae	0	0	0	0	0	0	0	0	0	3	6	13	5	3	0	6
Scrophulariaceae	17	32	40	14	26	8	5	11	5	0	3	0	0	13	0	7
Solanaceae	5	0	23	0	0	0	0	6	0	11	19	0	3	0	0	3
Thymelaeaceae	0	0	0	9	0	12	0	0	0	0	2	0	0	0	1	0
Typha	0	0	0	0	0	0	0	0	0	3	38	17	15	45	37	0
Unidentified	30	13	21	14	20	13	22	31	17	22	31	14	12	14	8	21
Zygophyllum	22	2	15	5	18	29	5	34	19	4	7	1	0	3	9	24
*Charcoal presence		*					*								**	***
Total organic carbon %	1.9	1.3	1.7	3.1	2.8	2.5	1.9	1.7	2.8	4.3	7.2	21.2	17.8	18.1	12.2	11.4
Pollen sum (less filicates)	449	502	502	414	426	526	520	520	417	566	669	618	391	684	430	484
Pollen grains g-1	4510	3498	7014	10114	6686	7244	8238	6250	8491	11640	19579	47727	31549	30508	19626	16993
Pollen grains cm-3	2873	2120	3525	5240	3910	3959	3850	3634	4717	7012	15918	54236	38475	32456	14222	12313

5. SPRING CAVE (SPC) TOTAL POLLEN COUNTS

Depth in cm	25	31	37	49	56	65	70	81	91	97	107
Radiocarbon years BP			1150			2970			3510		3890
Aizoaceae	13	0	0	5	0	2	0	0	16	10	17
Amaryllidaceae	0	0	0	0	3	2	3	0	3	0	0
Anacardiaceae	11	21	13	35	15	7	3	11	15	37	4
Asclepiadaceae	1	5	0	0	0	0	0	0	0	0	7
Asparagaceae	1	4	8	0	0	7	0	5	0	0	0
Asphodelaceae	3	0	18	0	0	0	0	0	0	0	0
Asteraceae *Stoebe* -type	22	10	26	7	14	37	27	11	17	5	12
Asteraceae (echinate)	57	27	23	38	73	97	82	48	113	129	117
Broken/obscured	8	12	12	27	47	21	33	12	22	10	18
Bruniaceae	2	1	0	1	18	13	7	0	3	1	4
Caryophyllaceae	3	0	0	0	0	0	0	0	0	0	0
Celastraceae	9	8	4	18	36	28	12	4	11	5	8
Chenopodiaceae	45	154	137	111	53	13	11	6	27	14	9
Crassulaceae	14	8	6	0	3	0	2	0	9	11	21
Cucurbitaceae	3	1	9	0	1	0	0	0	0	0	0
Cyperaceae	0	5	16	6	24	12	19	8	3	5	6
Drosera	7	3	0	0	5	12	3	0	0	0	0
Ebenaceae	19	59	18	13	44	48	7	36	12	17	11
Ericaceae	0	2	0	0	4	10	2	1	2	0	0
Euphorbiaceae	13	8	14	3	9	6	6	15	31	17	22
Fabaceae	18	13	11	29	16	39	29	45	12	21	36
Filicales	13	43	18	17	17	48	73	19	31	43	12
Geraniaceae	3	6	5	0	12	8	0	3	7	7	8
Hyacinthaceae	3	6	11	3	7	12	8	3	0	2	0
Iridaceae	3	4	5	0	5	3	7	2	6	0	3
Juncus	0	0	43	0	14	2	3	0	0	0	4
Lamiaceae	0	9	0	0	10	18	4	6	12	10	19
Limonium	5	12	5	6	0	0	0	0	0	0	0
Mesembryanthemaceae	22	7	25	14	18	37	28	5	22	15	21
Myrica	0	3	2	0	7	2	4	0	0	1	3
Olea	3	3	0	0	3	4	5	3	0	0	4
Oxalis	2	5	19	0	0	0	5	12	2	7	17
Poaceae <50µm	11	53	93	76	45	61	87	99	127	98	143
Poaceae >50µm	15	8	57	27	10	5	3	18	6	13	16
Podocarpus	4	0	0	1	6	10	2	11	7	0	5
Polygalaceae	0	5	3	8	12	3	0	0	0	0	0
Proteaceae	0	3	0	0	0	14	13	5	8	4	3
Pteridium (cf.)	4	21	6	7	25	17	13	6	5	3	4
Restionaceae	13	7	12	13	27	47	20	18	58	19	48
Rhamnaceae	5	6	0	14	0	17	6	11	14	2	5
Rosaceae	0	0	2	0	1	6	11	7	3	0	7
Rutaceae	0	0	3	0	0	0	3	4	0	2	0
Santalaceae	0	0	5	0	0	12	0	4	3	0	2
Scrophulariaceae	17	16	23	11	7	12	23	16	7	8	4
Solanaceae	1	4	0	7	0	5	0	0	12	9	14
Thymelaeaceae	8	7	0	0	15	19	13	3	11	7	10
Typha	0	0	33	0	0	0	0	0	0	0	0
Unidentified	9	17	13	18	13	11	23	13	21	31	12
Zostera (cf.)	0	0	8	0	0	0	0	0	0	0	0
Zygophyllum	1	5	1	19	0	12	7	32	29	22	20
*Charcoal presence	**				*	***	**	*			
Total organic carbon %	11.5	13.5	16.5	3.9	3.8	8.8	12.5	10.6	24.2	11.6	16.1
Pollen counts (less filicates)	365	548	689	517	602	691	534	483	656	542	664
Pollen grains g^{-1}	9944	13601	11489	8717	8557	22194	12678	13722	25078	11507	15494
Pollen grains cm^{-3}	6954	8775	8448	4764	5186	15098	8804	7978	13932	8461	11649

6. ELANDS BAY CAVE (EBC) TOTAL POLLEN COUNTS

DMS Sample number	DMS 138	DMS 142	DMS 144	DMS 147	DMS 149	DMS 150	DMS 87	DMS 88	DMS 119	DMS 120	DMS 121	DMS 122
Anacardiaceae	7	27	32	0	0	7	0	3	19	0	0	0
Aponogeton (cf.)	0	0	0	0	0	0	0	3	0	0	0	0
Asteraceae *Stoebe* -ty	2	4	18	0	0	0	16	62	0	0	0	0
Asteraceae (echinate	11	4	11	0	0	0	6	49	11	97	5	1
Broken/obscured	37	31	9	17	43	27	45	22	13	41	3	0
Celastraceae	25	18	8	0	0	11	13	9	38	0	0	0
Celtis	0	0	0	0	0	0	0	6	0	0	0	0
Drosera	0	0	0	0	0	0	0	13	0	0	0	0
Ebenaceae	16	13	14	0	0	0	0	1	13	0	0	0
Ericaceae	0	0	0	0	0	0	3	3	0	0	0	0
Ficus	0	0	0	0	0	0	0	0	6	0	0	0
Hyacinthaceae	0	0	0	0	0	0	0	8	0	0	0	0
Iridaceae	0	0	2	0	0	0	1	29	0	0	0	0
Kiggelaria	0	0	0	0	0	0	0	0	23	0	0	0
Lamiaceae	0	0	6	5	0	0	0	24	7	0	0	0
Mesembryanthemace	10	6	0	0	0	0	0	1	0	0	0	0
Myrica	0	0	0	0	0	0	0	0	5	0	0	0
Olea	0	0	8	0	0	0	15	25	14	0	0	0
Oxalis	0	0	0	0	0	0	0	9	0	0	0	0
Phragmites (cf.)	0	0	0	0	0	0	0	0	127	136	17	5
Poaceae undiff.	61	29	102	11	19	30	93	245	31	17	0	0
Podocarpus	0	0	0	0	0	0	9	0	2	0	0	0
Proteaceae	0	0	1	0	0	0	0	0	0	0	0	0
Restionaceae	19	2	15	0	0	9	0	2	0	0	0	0
Rosaceae	0	0	11	0	0	0	0	0	0	0	0	0
Salix	0	0	0	0	0	0	0	0	2	0	0	0
Santalaceae	5	0	0	0	0	0	0	10	0	0	0	0
Sapindaceae	12	3	4	7	0	3	0	8	4	0	0	0
Solanaceae	3	6	0	0	0	0	0	19	0	0	0	0
Unidentified	23	14	17	3	0	9	13	49	37	19	6	2
Zygophyllum	3	5	3	0	0	0	0	0	0	0	0	0
*Charcoal presence	**	*		*	*						*	
Pollen Sum	234	162	261	43	62	96	214	600	352	310	31	8
Pollen grains g^{-1}	1560	810	1740	172	248	384	1427	6316	2347	2067	124	32
Pollen grains cm^{-3}	811	454	818	95	129	207	699	3411	1572	1219	58	18

APPENDIX G

Calculations used to infer pollen concentrations and pollen accumulation rates

Each slide contains a measured aliquot of pollen which is taken to represent an accurate fraction of the final pollen suspension. Once all the pollen grains on the microscope slide(s) have been counted, the total number of grains in the final suspension may then be extrapolated as follows, viz:

$$P_{final\ suspension} = (P_{counted} \times [\{50/ T_{counted}\} \times \{V_{final\ suspension}\ ml/ V_{aliquot}\ ml\}]), \quad \text{where...}$$

$P_{counted}$ = Pollen counted.
$T_{counted}$ = Traverses counted.
$V_{final\ suspension}$ = Volume of final suspension, expressed in ml.
$V_{aliquot}$ = Volume of aliquot, expressed in ml.

Given the total number of pollen grains in the final suspension, it follows that the pollen concentration in grains per unit mass (grains g^{-1}) of each original moist sediment sample may then be calculated as follows:

$$P_{concentration\ g^{-1}} = (P_{final\ suspension} / M_{sample\ in\ g}), \quad \text{where...}$$

$P_{final\ suspension}$ = Total pollen in final suspension.
M_{sample} = Mass of original sample, expressed in g.

If the relationship between volume and mass of the original sample was established (eg during the loss-on-ignition (LOI) procedure), it follows that pollen concentration can be calculated in grains per unit volume (grains cm^{-3}) of each original moist sediment sample, calculated as follows:

$$P_{concentration\ cm^{-3}} = (P_{final\ suspension} / V_{sample\ in\ cm^3}), \quad \text{where...}$$

$P_{final\ suspension}$ = Total pollen in final suspension.
V_{sample} = Volume of original sample, expressed in cm^3.*

* Calculated on the basis of the relationship between volume and mass, established during the loss-on-ignition (LOI) procedure described in section 7.3.1.

Finally, pollen accumulation rates (grains cm^{-2} $year^{-1}$) can be computed by referring to the sediment accumulation rates, established by accurate age determinations of the sediment profiles, viz:

$\mathbf{P}_{accumulation}$ cm^{-2} $year^{-1}$ = ($\mathbf{P}_{concentration}$ cm^{-3} X $\mathbf{S}_{accumulation}$ cm $year^{-1}$), where...

$\mathbf{P}_{concentration}$ cm^{-3} = Pollen concentration, expressed in grains cm^{-3}.

$\mathbf{S}_{accumulation}$ cm $year^{-1}$ = Sediment accumulation, expressed in cm $year^{-1}$.

APPENDIX H

Nearest Neighbour Indices (NNIs) for the Sandveld pollen spectra

NNI ref.	LOCATION	DESCRIPTION
C01	Piketberg uplands	Mature Dry Mountain Fynbos on Piketberg including stands of *Leucadendron*, *Protea* and *Passerina* spp.
C02	Wadrifsoutpan	Extensive saltmarsh and hypersaline pond along the coast. *Spartina*, *Salicornia* and *Chenolea* spp. dominate.
C03	Klaarfontein Spring	Damp (disturbed) organic deposit near source of spring. Sedges, grasses, Arum lilies and ruderal weeds.
C04	Redelinghuys wetland	Riparian vegetatiom along the western margin of the Redelinghuys wetland among dried out *Typha* beds.
C05	Rooikrans koppie	Restioid Strandveld on the eastern slopes above Grootdrift. Abundant restios and *Euphorbia* spp.
C06	Grootdrift Farm	Degraded (overgrazed) Dry Mountain Fynbos among rocky slopes above western margin of Verlorenvlei.
C07	Diepkloof Farm	Heavily grazed Strandveld/ fynbos vegetation on the slopes below Diepkloof Cave near large *Ficus* specimen.
C08	Diepkloof Cave	Admix of Karroid Strandveld, fynbos and Scrub Forest near Diepkloof Cave. *Rhus, Crassula* and *Olea* spp.
C09	Muishoek fringe	Shrubby Strandveld above the *Phragmites* skirt along westen shore of Verlorenvlei embayment.
C10	Grootdrift coring site	Surface muds sampled among dense reed beds of the transitional wetland. *Typha, Phragmites, Juncus* spp.
C11	Verlorenvlei embayment	Coastal Strandveld near the main Verlorenvlei embayment. *Juncus, Cyperus, Crassula, Lampranthus* spp
C12	Muishoekberg	Degraded Karroid Strandveld. Dominated by unpalatable spp. eg, *Euphorbia* & *Crassula*.
C13	Bloukop grove	Afromontane Scrub Forest among the gullies on Uitkykberg, including *Podocarpus elongatus* and *Olea*.
C14	Bloubak se koppe	Pristine Dry Mountain Fynbos among rocky mountain slopes. Including *Olea*, *Maytenus* and *Rhus* spp.
C15	Verlorenvlei mouth	Saline-tolerant vegetation on seaward side of causeway at Elands Bay. *Spartina*, *Salicornia*, *Juncus* spp.
C16	Uithoek	Restioid Lowland Fynbos among rolling hills opposite Staanklipbult. Abundant *Willdenowia* spp.
C17	Muisbosskerm	Straggling Coastal Strandveld among primary dune cordon. Asteraceous shrubs dominate.
C18	Spring Cave	Sample collected from damp profile in front of water seep. *Oxalis*, Restios and ferns.

Table H.1 The list of reference numbers relating to each of the modern (surface) sites used in the determination of the Nearest Neighbour Indices (NNIs). For details, refer to Chapters 8 and 9 and see below.

Site: GDV4. Depth 00 cm.	SITE AND SAMPLE DETAILS
0. 11. 3. 0. 0. 3. 18. 0. 0. 184. 0. 3. 19. 0. 0. 9. 0. 3. 0. 12. 0. 31. 0. 7. 0. 0. 25. 24. 0. 33. 0. 0. 12. 6. 25. 0. 0. 0. 13. 12. 0. 0. 0. 19. 6. 0. 43. 0. 0. 0. 0. 0. 0. 0. 0. 12.	Original pollen counts obtained from Appendix F
.0000 .0206 .0056 .0000 .0000 .0056 .0338 .0000 .0000 .3452 .0000 .0056 .0356 .0000 .0000 .0169 .0000 .0056 .0000 .0225 .0000 .0582 .0000 .0131 .0000 .0000 .0469 .0450 .0000 .0619 .0000 .0000 .0225 .0113 .0469 .0000 .0000 .0000 .0244 .0225 .0000 .0000 .0000 .0356 .0113 .0000 .0807 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0225	Pollen counts converted to proportions
.37 .52 .27 .30 .32 .26 .26 .27 .25 .23 .30 .29 .33 .38 .42 .39 .27 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.23 .25 .26 .26 .27 .27 .27 .29 .30 .30 .31 .32 .33 .37 .38 .39 .42 .52	Euclidian 'distances' sorted from smallest to largest
C10 C09 C06 C07 C08 C17 C03 C12 C11 C04 C18 C05 C13 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 05 cm.	SITE AND SAMPLE DETAILS
0. 4. 6. 0. 4. 6. 8. 0. 0. 167. 0. 5. 35. 0. 0. 12. 0. 0. 0. 6. 0. 51. 0. 3. 0. 0. 20. 14. 0. 14. 0. 0. 16. 3. 35. 0. 0. 0. 3. 7. 0. 0. 6. 20. 3. 0. 72. 0. 0. 0. 0. 0. 0. 3. 0. 10.	Original pollen counts obtained from Appendix F
.0000 .0075 .0113 .0000 .0075 .0113 .0150 .0000 .0000 .3133 .0000 .0094 .0657 .0000 .0000 .0225 .0000 .0000 .0000 .0113 .0000 .0957 .0000 .0056 .0000 .0000 .0375 .0263 .0000 .0263 .0000 .0000 .0300 .0056 .0657 .0000 .0000 .0000 .0056 .0131 .0000 .0000 .0113 .0375 .0056 .0000 .1351 .0000 .0000 .0000 .0000 .0000 .0000 .0056 .0000 .0188	Pollen counts converted to proportions
.36 .49 .24 .26 .31 .27 .27 .27 .24 .22 .27 .29 .32 .36 .40 .38 .27 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .24 .24 .26 .27 .27 .27 .27 .27 .29 .31 .32 .32 .36 .36 .38 .40 .49	Euclidian 'distances' sorted from smallest to largest
C10 C03 C09 C04 C07 C06 C11 C08 C17 C12 C05 C18 C13 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 10 cm.	SITE AND SAMPLE DETAILS
0. 3. 12. 0. 0. 3. 12. 0. 0. 95. 0. 9. 24. 0. 0. 12. 0. 0. 0. 0. 0. 44. 0. 1. 0. 0. 10. 13. 0. 18. 0. 0. 18. 6. 21. 0. 0. 0. 3. 0. 0. 0. 0. 12. 1. 0. 59. 0. 0. 0. 0. 0. 0. 0. 0. 4.	Original pollen counts obtained from Appendix F
.0000 .0079 .0316 .0000 .0000 .0079 .0316 .0000 .0000 .2500 .0000 .0237 .0632 .0000 .0000 .0316 .0000 .0000 .0000 .0000 .0000 .1158 .0000 .0026 .0000 .0000 .0263 .0342 .0000 .0474 .0000 .0000 .0474 .0158 .0553 .0000 .0000 .0000 .0079 .0000 .0000 .0000 .0000 .0316 .0026 .0000 .1553 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0105	Pollen counts converted to proportions
.34 .47 .21 .23 .29 .28 .27 .28 .23 .21 .26 .30 .29 .34 .36 .37 .28 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .21 .23 .23 .26 .27 .28 .28 .28 .29 .29 .30 .30 .34 .34 .36 .37 .47	Euclidian 'distances' sorted from smallest to largest
C03 C10 C04 C09 C11 C07 C08 C17 C06 C13 C05 C18 C12 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 15 cm.	SITE AND SAMPLE DETAILS
0. 12. 21. 5. 10. 13. 7. 0. 0. 129. 0. 1. 18. 0. 7. 6. 0. 0. 0. 0. 0. 46. 0. 3. 0. 0. 4. 15. 0. 45. 6. 0. 14. 21. 55. 0. 0. 0. 9. 0. 0. 0. 6. 7. 1. 0. 117. 0. 0. 0. 0. 3. 0. 0. 0. 10.	Original pollen counts obtained from Appendix F
.0000 .0203 .0355 .0085 .0169 .0220 .0118 .0000 .0000 .2183 .0000 .0017 .0305 .0000 .0118 .0102 .0000 .0000 .0000 .0000 .0000 .0778 .0000 .0051 .0000 .0000 .0068 .0254 .0000 .0761 .0102 .0000 .0237 .0355 .0931 .0000 .0000 .0000 .0152 .0000 .0000 .0000 .0102 .0118 .0017 .0000 .1980 .0000 .0000 .0000 .0000 .0051 .0000 .0000 .0000 .0169	Pollen counts converted to proportions
.33 .44 .23 .24 .29 .29 .27 .28 .24 .23 .24 .31 .29 .34 .33 .36 .28 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.23 .23 .24 .24 .24 .27 .28 .28 .29 .29 .29 .30 .31 .33 .33 .34 .36 .44	Euclidian 'distances' sorted from smallest to largest
C10 C03 C09 C04 C11 C07 C17 C08 C05 C06 C13 C18 C12 C01 C15 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 20 cm.	**SITE AND SAMPLE DETAILS**
0. 3. 12. 4. 7. 0. 3. 0. 0. 49. 0. 0. 23. 0. 0. 3. 0. 0. 0. 3. 0. 35. 0. 0. 0. 0. 11. 7. 0. 19. 3. 0. 4. 0. 16. 0. 0. 0. 0. 0. 0. 0. 3. 3. 1. 0. 57. 0. 0. 0. 0. 3. 0. 9. 0. 10.	Original pollen counts obtained from Appendix F
.0000 .0104 .0417 .0139 .0243 .0000 .0104 .0000 .0000 .1701 .0000 .0000 .0799 .0000 .0000 .0104 .0000 .0000 .0000 .0104 .0000 .1215 .0000 .0000 .0000 .0000 .0382 .0243 .0000 .0660 .0104 .0000 .0139 .0000 .0556 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0104 .0104 .0035 .0000 .1979 .0000 .0000 .0000 .0000 .0104 .0000 .0313 .0000 .0347	Pollen counts converted to proportions
.29 .44 .21 .22 .27 .30 .29 .29 .25 .23 .25 .32 .28 .32 .33 .35 .30 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .22 .23 .25 .25 .27 .28 .29 .29 .29 .30 .30 .30 .32 .32 .33 .35 .44	Euclidian 'distances' sorted from smallest to largest
C03 C04 C10 C11 C09 C05 C13 C08 C07 C01 C18 C17 C06 C12 C14 C15 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 25 cm.	**SITE AND SAMPLE DETAILS**
0. 10. 3. 0. 0. 9. 0. 0. 0. 66. 0. 0. 30. 0. 0. 6. 0. 6. 0. 6. 0. 81. 0. 0. 0. 0. 13. 11. 0. 33. 5. 0. 15. 10. 38. 0. 0. 0. 0. 0. 0. 0. 2. 4. 0. 0. 138. 0. 0. 6. 0. 4. 0. 12. 0. 23.	Original pollen counts obtained from Appendix F
.0000 .0188 .0056 .0000 .0000 .0169 .0000 .0000 .0000 .1243 .0000 .0000 .0565 .0000 .0000 .0113 .0000 .0113 .0000 .0113 .0000 .1525 .0000 .0000 .0000 .0000 .0245 .0207 .0000 .0621 .0094 .0000 .0282 .0188 .0716 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0038 .0075 .0000 .0000 .2599 .0000 .0000 .0113 .0000 .0075 .0000 .0226 .0000 .0433	Pollen counts converted to proportions
.33 .43 .24 .24 .30 .36 .33 .34 .29 .28 .27 .36 .32 .35 .32 .37 .35 .34	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.24 .24 .27 .28 .29 .30 .32 .32 .33 .33 .34 .34 .35 .35 .36 .36 .37 .43	Euclidian 'distances' sorted from smallest to largest
C04 C03 C11 C10 C09 C05 C15 C13 C01 C07 C18 C08 C17 C14 C06 C12 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 30 cm.	SITE AND SAMPLE DETAILS
0. 6. 14. 0. 11. 0. 0. 0. 0. 93. 0. 0. 18. 0. 0. 3. 0. 10. 0. 7. 0. 81. 0. 0. 6. 0. 6. 10. 0. 45. 14. 0. 27. 6. 36. 0. 0. 0. 0. 0. 0. 0. 5. 0. 0. 0. 87. 0. 0. 5. 0. 0. 0. 13. 0. 37.	Original pollen counts obtained from Appendix F
.0000 .0111 .0259 .0000 .0204 .0000 .0000 .0000 .0000 .1722 .0000 .0000 .0333 .0000 .0000 .0056 .0000 .0185 .0000 .0130 .0000 .1500 .0000 .0000 .0111 .0000 .0111 .0185 .0000 .0833 .0259 .0000 .0500 .0111 .0667 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0093 .0000 .0000 .0000 .1611 .0000 .0000 .0093 .0000 .0000 .0000 .0241 .0000 .0685	Pollen counts converted to proportions
.29 .44 .19 .20 .27 .31 .29 .29 .25 .23 .26 .33 .30 .33 .33 .33 .31 .29	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .20 .23 .25 .26 .27 .29 .29 .29 .29 .30 .31 .31 .33 .33 .33 .33 .44	Euclidian 'distances' sorted from smallest to largest
C03 C04 C10 C09 C11 C05 C18 C01 C07 C08 C13 C06 C17 C14 C16 C15 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 35 cm.	**SITE AND SAMPLE DETAILS**
0. 4. 6. 5. 13. 0. 0. 0. 0. 91. 0. 0. 30. 0. 0. 15. 0. 4. 0. 0. 0. 33. 0. 0. 0. 0. 0. 2. 0. 21. 0. 0. 15. 3. 9. 0. 0. 0. 6. 0. 0. 10. 2. 0. 0. 0. 103. 0. 0. 10. 0. 0. 0. 17. 0. 29.	Original pollen counts obtained from Appendix F
.0000 .0093 .0140 .0117 .0304 .0000 .0000 .0000 .0000 .2126 .0000 .0000 .0701 .0000 .0000 .0350 .0000 .0093 .0000 .0000 .0000 .0771 .0000 .0000 .0000 .0000 .0000 .0047 .0000 .0491 .0000 .0000 .0350 .0070 .0210 .0000 .0000 .0000 .0140 .0000 .0000 .0234 .0047 .0000 .0000 .0000 .2407 .0000 .0000 .0234 .0000 .0000 .0000 .0397 .0000 .0678	Pollen counts converted to proportions
.31 .45 .25 .26 .26 .30 .29 .30 .26 .26 .27 .32 .30 .33 .34 .33 .30 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.25 .26 .26 .26 .26 .27 .29 .30 .30 .30 .30 .31 .31 .32 .33 .33 .34 .45	Euclidian 'distances' sorted from smallest to largest
C03 C10 C09 C05 C04 C11 C07 C08 C06 C17 C13 C18 C01 C12 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 40 cm.	**SITE AND SAMPLE DETAILS**
0. 7. 3. 0. 9. 0. 3. 0. 0. 121. 0. 0. 19. 0. 6. 6. 0. 10. 0. 6. 0. 48. 0. 12. 6. 0. 14. 0. 0. 18. 0. 0. 9. 2. 6. 0. 0. 0. 1. 0. 0. 13. 3. 27. 0. 0. 97. 0. 0. 6. 0. 6. 0. 14. 0. 15.	Original pollen counts obtained from Appendix F
.0000 .0144 .0062 .0000 .0185 .0000 .0062 .0000 .0000 .2485 .0000 .0000 .0390 .0000 .0123 .0123 .0000 .0205 .0000 .0123 .0000 .0986 .0000 .0246 .0123 .0000 .0287 .0000 .0000 .0370 .0000 .0000 .0185 .0041 .0123 .0000 .0000 .0000 .0021 .0000 .0000 .0267 .0062 .0554 .0000 .0000 .1992 .0000 .0000 .0123 .0000 .0123 .0000 .0287 .0000 .0308	Pollen counts converted to proportions
.32 .45 .22 .24 .28 .27 .27 .27 .24 .23 .26 .30 .30 .34 .35 .36 .27 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .23 .24 .24 .26 .27 .27 .27 .27 .28 .30 .30 .30 .32 .34 .35 .36 .45	Euclidian 'distances' sorted from smallest to largest
C03 C10 C04 C09 C11 C07 C06 C08 C17 C05 C12 C18 C13 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 45 cm.	SITE AND SAMPLE DETAILS
0. 4. 6. 2. 9. 1. 0. 0. 0. 115. 0. 0. 25. 0. 6. 10. 0. 3. 0. 3. 0. 65. 0. 0. 7. 0. 11. 10. 0. 9. 9. 0. 30. 0. 33. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 90. 0. 0. 14. 0. 0. 8. 15. 0. 39.	Original pollen counts obtained from Appendix F
.0000 .0076 .0115 .0038 .0172 .0019 .0000 .0000 .0000 .2195 .0000 .0000 .0477 .0000 .0115 .0191 .0000 .0057 .0000 .0057 .0000 .1240 .0000 .0000 .0134 .0000 .0210 .0191 .0000 .0172 .0172 .0000 .0573 .0000 .0630 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1718 .0000 .0000 .0267 .0000 .0000 .0153 .0286 .0000 .0744	Pollen counts converted to proportions
.30 .45 .21 .22 .25 .28 .27 .28 .25 .22 .25 .31 .29 .32 .35 .32 .29 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .22 .22 .25 .25 .25 .27 .28 .28 .29 .29 .30 .30 .31 .32 .32 .35 .45	Euclidian 'distances' sorted from smallest to largest
C03 C10 C04 C09 C05 C11 C07 C08 C06 C13 C17 C01 C18 C12 C16 C14 C15 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 50 cm.	**SITE AND SAMPLE DETAILS**
0. 2. 7. 3. 0. 4. 0. 0. 0. 75. 0. 0. 29. 0. 3. 7. 0. 6. 0. 9. 0. 34. 0. 0. 0. 0. 7. 3. 0. 44. 3. 0. 34. 5. 25. 0. 0. 0. 12. 0. 0. 7. 6. 0. 0. 0. 81. 0. 0. 5. 0. 0. 15. 16. 0. 16.	Original pollen counts obtained from Appendix F
.0000 .0044 .0153 .0066 .0000 .0087 .0000 .0000 .0000 .1638 .0000 .0000 .0633 .0000 .0066 .0153 .0000 .0131 .0000 .0197 .0000 .0742 .0000 .0000 .0000 .0000 .0153 .0066 .0000 .0961 .0066 .0000 .0742 .0109 .0546 .0000 .0000 .0000 .0262 .0000 .0000 .0153 .0131 .0000 .0000 .0000 .1769 .0000 .0000 .0109 .0000 .0000 .0328 .0349 .0000 .0349	Pollen counts converted to proportions
.28 .42 .22 .24 .26 .29 .28 .27 .24 .22 .24 .31 .26 .30 .32 .33 .29 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .22 .24 .24 .24 .26 .26 .27 .27 .28 .28 .29 .29 .30 .31 .32 .33 .42	Euclidian 'distances' sorted from smallest to largest
C03 C10 C09 C04 C11 C05 C13 C18 C08 C07 C01 C17 C06 C14 C12 C15 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 55 cm.	**SITE AND SAMPLE DETAILS**
0. 3. 0. 1. 6. 0. 9. 0. 0. 89. 0. 0. 12. 0. 0. 13. 0. 3. 0. 10. 0. 19. 0. 0. 2. 0. 10. 1. 0. 27. 0. 0. 19. 7. 38. 0. 0. 0. 5. 0. 6. 0. 6. 1. 0. 0. 108. 0. 0. 5. 0. 0. 16. 15. 0. 20.	Original pollen counts obtained from Appendix F
.0000 .0067 .0000 .0022 .0133 .0000 .0200 .0000 .0000 .1973 .0000 .0000 .0266 .0000 .0000 .0288 .0000 .0067 .0000 .0222 .0000 .0421 .0000 .0000 .0044 .0000 .0222 .0022 .0000 .0599 .0000 .0000 .0421 .0155 .0843 .0000 .0000 .0000 .0111 .0000 .0133 .0000 .0133 .0022 .0000 .0000 .2395 .0000 .0000 .0111 .0000 .0000 .0355 .0333 .0000 .0443	Pollen counts converted to proportions
.32 .43 .26 .27 .27 .30 .28 .29 .26 .25 .24 .31 .30 .33 .33 .34 .30 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.24 .25 .26 .26 .27 .27 .28 .29 .30 .30 .30 .31 .31 .32 .33 .33 .34 .43	Euclidian 'distances' sorted from smallest to largest
C11 C10 C09 C03 C04 C05 C07 C08 C17 C06 C13 C18 C12 C01 C15 C14 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 60 cm.	SITE AND SAMPLE DETAILS
0. 7. 6. 0. 13. 0. 0. 0. 0. 55. 0. 0. 26. 0. 0. 15. 0. 0. 0. 3. 0. 9. 0. 2. 3. 0. 8. 6. 0. 29. 0. 0. 36. 3. 9. 0. 0. 0. 0. 0. 2. 13. 12. 0. 0. 0. 93. 0. 0. 6. 0. 0. 17. 9. 0. 28.	Original pollen counts obtained from Appendix F
.0000 .0171 .0146 .0000 .0317 .0000 .0000 .0000 .0000 .1341 .0000 .0000 .0634 .0000 .0000 .0366 .0000 .0000 .0000 .0073 .0000 .0220 .0000 .0049 .0073 .0000 .0195 .0146 .0000 .0707 .0000 .0000 .0878 .0073 .0220 .0000 .0000 .0000 .0000 .0000 .0049 .0317 .0293 .0000 .0000 .0000 .2268 .0000 .0000 .0146 .0000 .0000 .0415 .0220 .0000 .0683	Pollen counts converted to proportions
.29 .43 .27 .30 .25 .32 .30 .29 .27 .27 .27 .33 .27 .30 .33 .31 .31 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.25 .27 .27 .27 .27 .27 .29 .29 .30 .30 .30 .30 .31 .31 .32 .33 .33 .43	Euclidian 'distances' sorted from smallest to largest
C05 C10 C13 C11 C03 C09 C01 C08 C04 C07 C14 C18 C16 C17 C06 C15 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 65 cm.	**SITE AND SAMPLE DETAILS**
0. 5. 3. 6. 12. 0. 0. 0. 0. 46. 0. 0. 9. 0. 0. 15. 0. 6. 0. 7. 0. 27. 0. 0. 0. 0. 2. 5. 0. 15. 0. 0. 11. 2. 18. 0. 0. 0. 3. 0. 4. 20. 10. 0. 0. 0. 96. 0. 0. 7. 0. 0. .7. 6. 0. 18.	Original pollen counts obtained from Appendix F
.0000 .0139 .0083 .0167 .0333 .0000 .0000 .0000 .0000 .1278 .0000 .0000 .0250 .0000 .0000 .0417 .0000 .0167 .0000 .0194 .0000 .0750 .0000 .0000 .0000 .0000 .0056 .0139 .0000 .0417 .0000 .0000 .0306 .0056 .0500 .0000 .0000 .0000 .0083 .0000 .0111 .0556 .0278 .0000 .0000 .0000 .2667 .0000 .0000 .0194 .0000 .0000 .0194 .0167 .0000 .0500	Pollen counts converted to proportions
.31 .41 .26 .27 .28 .34 .31 .31 .28 .28 .26 .35 .29 .32 .31 .34 .33 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.26 .26 .27 .28 .28 .28 .29 .31 .31 .31 .31 .31 .32 .33 .34 .34 .35 .41	Euclidian 'distances' sorted from smallest to largest
C11 C03 C04 C10 C05 C09 C13 C15 C08 C01 C07 C18 C14 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 70 cm.	**SITE AND SAMPLE DETAILS**
0. 0. 2. 0. 14. 0. 0. 0. 0. 25. 0. 0. 21. 0. 0. 12. 0. 4. 0. 0. 0. 15. 0. 0. 0. 0. 1. 6. 0. 26. 0. 0. 21. 0. 15. 0. 0. 0. 0. 0. 3. 30. 2. 0. 0. 0. 77. 0. 0. 9. 0. 0. 13. 7. 0. 6.	Original pollen counts obtained from Appendix F
.0000 .0000 .0065 .0000 .0453 .0000 .0000 .0000 .0000 .0809 .0000 .0000 .0680 .0000 .0000 .0388 .0000 .0129 .0000 .0000 .0000 .0485 .0000 .0000 .0000 .0000 .0032 .0194 .0000 .0841 .0000 .0000 .0680 .0000 .0485 .0000 .0000 .0000 .0000 .0000 .0097 .0971 .0065 .0000 .0000 .0000 .2492 .0000 .0000 .0291 .0000 .0000 .0421 .0227 .0000 .0194	Pollen counts converted to proportions
.33 .42 .29 .30 .31 .37 .35 .35 .31 .31 .29 .38 .29 .32 .32 .37 .36 .33	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.29 .29 .29 .30 .31 .31 .31 .32 .32 .33 .33 .35 .35 .36 .37 .37 .38 .42	Euclidian 'distances' sorted from smallest to largest
C03 C13 C11 C04 C10 C05 C09 C14 C15 C01 C18 C08 C07 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 75 cm.	SITE AND SAMPLE DETAILS
0. 0. 0. 6. 16. 2. 0. 0. 0. 32. 0. 0. 18. 0. 0. 16. 0. 6. 0. 2. 0. 17. 0. 0. 0. 0. 4. 4. 0. 36. 3. 0. 18. 0. 15. 0. 0. 0. 0. 0. 9. 34. 3. 0. 0. 0. 71. 0. 0. 3. 0. 0. 18. 3. 0. 12.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0172 .0460 .0057 .0000 .0000 .0000 .0920 .0000 .0000 .0517 .0000 .0000 .0460 .0000 .0172 .0000 .0057 .0000 .0489 .0000 .0000 .0000 .0000 .0115 .0115 .0000 .1034 .0086 .0000 .0517 .0000 .0431 .0000 .0000 .0000 .0000 .0000 .0259 .0977 .0086 .0000 .0000 .0000 .2040 .0000 .0000 .0086 .0000 .0000 .0517 .0086 .0000 .0345	Pollen counts converted to proportions
.31 .42 .27 .29 .29 .35 .32 .32 .29 .28 .28 .36 .28 .31 .32 .34 .33 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.27 .28 .28 .28 .29 .29 .29 .30 .31 .31 .32 .32 .32 .33 .34 .35 .36 .42	Euclidian 'distances' sorted from smallest to largest
C03 C13 C10 C11 C05 C04 C09 C18 C01 C14 C08 C15 C07 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 80 cm.	**SITE AND SAMPLE DETAILS**
0. 0. 0. 3. 9. 0. 1. 0. 0. 31. 0. 0. 27. 0. 2. 12. 0. 3. 0. 3. 0. 18. 0. 0. 0. 0. 7. 9. 0. 23. 0. 0. 27. 0. 9. 0. 0. 0. 7. 0. 9. 31. 0. 0. 0. 0. 109. 0. 0. 2. 0. 0. 14. 4. 0. 16.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0080 .0239 .0000 .0027 .0000 .0000 .0824 .0000 .0000 .0718 .0000 .0053 .0319 .0000 .0080 .0000 .0080 .0000 .0479 .0000 .0000 .0000 .0000 .0186 .0239 .0000 .0612 .0000 .0000 .0718 .0000 .0239 .0000 .0000 .0000 .0186 .0000 .0239 .0824 .0000 .0000 .0000 .0000 .2899 .0000 .0000 .0053 .0000 .0000 .0372 .0106 .0000 .0426	Pollen counts converted to proportions
.34 .43 .31 .32 .30 .38 .35 .35 .32 .32 .30 .38 .31 .35 .33 .37 .36 .34	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.30 .30 .31 .31 .32 .32 .32 .33 .34 .34 .35 .35 .35 .36 .37 .38 .38 .43	Euclidian 'distances' sorted from smallest to largest
C11 C05 C03 C13 C04 C10 C09 C15 C01 C18 C14 C08 C07 C17 C16 C12 C06 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 85 cm.	**SITE AND SAMPLE DETAILS**
0. 3. 14. 3. 17. 0. 0. 0. 0. 64. 0. 0. 9. 0. 5. 17. 0. 6. 0. 7. 0. 23. 0. 3. 18. 0. 16. 3. 0. 33. 0. 0. 19. 10. 21. 0. 0. 0. 0. 0. 18. 84. 15. 2. 0. 0. 137. 0. 0. 10. 0. 0. 29. 16. 0. 24.	Original pollen counts obtained from Appendix F
.0000 .0048 .0224 .0048 .0272 .0000 .0000 .0000 .0000 .1022 .0000 .0000 .0144 .0000 .0080 .0272 .0000 .0096 .0000 .0112 .0000 .0367 .0000 .0048 .0288 .0000 .0256 .0048 .0000 .0527 .0000 .0000 .0304 .0160 .0335 .0000 .0000 .0000 .0000 .0000 .0288 .1342 .0240 .0032 .0000 .0000 .2188 .0000 .0000 .0160 .0000 .0000 .0463 .0256 .0000 .0383	Pollen counts converted to proportions
.30 .42 .28 .30 .29 .34 .32 .31 .30 .29 .28 .35 .28 .31 .33 .34 .33 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.28 .28 .28 .29 .29 .30 .30 .30 .31 .31 .31 .32 .33 .33 .34 .34 .35 .42	Euclidian 'distances' sorted from smallest to largest
C11 C03 C13 C10 C05 C09 C04 C01 C14 C18 C08 C07 C15 C17 C06 C16 C12 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 90 cm.	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 0. 0. 3. 0. 0. 46. 0. 0. 14. 0. 3. 10. 0. 3. 4. 2. 0. 21. 0. 0. 3. 0. 13. 0. 0. 16. 0. 0. 20. 2. 6. 0. 0. 0. 0. 0. 12. 67. 9. 1. 0. 0. 106. 0. 0. 5. 0. 0. 25. 7. 0. 25.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0071 .0000 .0000 .1087 .0000 .0000 .0331 .0000 .0071 .0236 .0000 .0071 .0095 .0047 .0000 .0496 .0000 .0000 .0071 .0000 .0307 .0000 .0000 .0378 .0000 .0000 .0473 .0047 .0142 .0000 .0000 .0000 .0000 .0000 .0284 .1584 .0213 .0024 .0000 .0000 .2506 .0000 .0000 .0118 .0000 .0000 .0591 .0165 .0000 .0591	Pollen counts converted to proportions
.33 .44 .30 .31 .30 .37 .34 .34 .32 .31 .31 .37 .31 .34 .35 .36 .36 .35	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.30 .30 .31 .31 .31 .31 .32 .33 .34 .34 .34 .35 .35 .36 .36 .37 .37 .44	Euclidian 'distances' sorted from smallest to largest
C05 C03 C11 C10 C13 C04 C09 C01 C14 C08 C07 C18 C15 C16 C17 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 95 cm.	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 13. 0. 0. 0. 0. 49. 0. 0. 14. 0. 0. 9. 0. 8. 1. 7. 0. 22. 0. 0. 0. 0. 9. 5. 0. 20. 0. 0. 14. 0. 3. 0. 0. 0. 0. 0. 12. 40. 1. 0. 0. 0. 117. 0. 0. 1. 0. 0. 13. 3. 0. 6.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0354 .0000 .0000 .0000 .0000 .1335 .0000 .0000 .0381 .0000 .0000 .0245 .0000 .0218 .0027 .0191 .0000 .0599 .0000 .0000 .0000 .0000 .0245 .0136 .0000 .0545 .0000 .0000 .0381 .0000 .0082 .0000 .0000 .0000 .0000 .0000 .0327 .1090 .0027 .0000 .0000 .0000 .3188 .0000 .0000 .0027 .0000 .0000 .0354 .0082 .0000 .0163	Pollen counts converted to proportions
.37 .44 .32 .32 .34 .38 .36 .36 .33 .33 .31 .38 .34 .38 .35 .40 .36 .36	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.31 .32 .32 .33 .33 .34 .34 .35 .36 .36 .36 .36 .37 .38 .38 .38 .40 .44	Euclidian 'distances' sorted from smallest to largest
C11 C04 C03 C10 C09 C05 C13 C15 C07 C08 C17 C18 C01 C14 C06 C12 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 100 cm.	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 15. 6. 0. 0. 0. 54. 0. 0. 12. 0. 5. 0. 0. 6. 6. 10. 0. 19. 0. 0. 0. 0. 11. 3. 0. 25. 0. 0. 12. 0. 10. 0. 0. 0. 0. 0. 9. 52. 13. 0. 0. 0. 141. 0. 0. 12. 0. 0. 12. 3. 0. 28.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0323 .0129 .0000 .0000 .0000 .1164 .0000 .0000 .0259 .0000 .0108 .0000 .0000 .0129 .0129 .0216 .0000 .0409 .0000 .0000 .0000 .0000 .0237 .0065 .0000 .0539 .0000 .0000 .0259 .0000 .0216 .0000 .0000 .0000 .0000 .0000 .0194 .1121 .0280 .0000 .0000 .0000 .3039 .0000 .0000 .0259 .0000 .0000 .0259 .0065 .0000 .0603	Pollen counts converted to proportions
.35 .44 .32 .32 .31 .37 .35 .35 .33 .32 .30 .37 .33 .35 .34 .37 .36 .35	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.30 .31 .32 .32 .32 .33 .33 .34 .35 .35 .35 .35 .35 .36 .37 .37 .37 .44	Euclidian 'distances' sorted from smallest to largest
C11 C05 C03 C04 C10 C09 C13 C15 C14 C08 C07 C01 C18 C17 C16 C12 C06 C02	Reference numbers of the corresponding modern sites

Site: GDV4. Depth 110 cm.	SITE AND SAMPLE DETAILS
0. 0. 6. 0. 29. 1. 0. 0. 0. 32. 0. 0. 9. 0. 0. 11. 0. 10. 11. 0. 0. 6. 0. 0. 0. 0. 3. 0. 0. 32. 0. 0. 9. 2. 0. 0. 0. 0. 0. 0. 12. 27. 2. 0. 0. 0. 87. 0. 0. 0. 0. 0. 6. 0. 0. 18.	Original pollen counts obtained from Appendix F
.0000 .0000 .0192 .0000 .0927 .0032 .0000 .0000 .0000 .1022 .0000 .0000 .0288 .0000 .0000 .0351 .0000 .0319 .0351 .0000 .0000 .0192 .0000 .0000 .0000 .0000 .0096 .0000 .0000 .1022 .0000 .0000 .0288 .0064 .0000 .0000 .0000 .0000 .0000 .0000 .0383 .0863 .0064 .0000 .0000 .0000 .2780 .0000 .0000 .0000 .0000 .0000 .0192 .0000 .0000 .0575	Pollen counts converted to proportions
.35 .43 .32 .33 .31 .38 .35 .36 .33 .33 .31 .38 .33 .35 .34 .36 .36 .34	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.31 .31 .32 .33 .33 .33 .33 .34 .34 .35 .35 .35 .36 .36 .36 .38 .38 .43	Euclidian 'distances' sorted from smallest to largest
C05 C11 C03 C09 C10 C13 C04 C15 C18 C01 C07 C14 C08 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 115 cm.	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 40. 1. 0. 0. 0. 54. 0. 0. 30. 0. 3. 13. 0. 24. 5. 10. 0. 15. 0. 3. 0. 0. 0. 9. 0. 13. 0. 0. 30. 6. 10. 0. 0. 0. 3. 0. 18. 39. 18. 3. 0. 0. 144. 0. 0. 6. 0. 0. 10. 9. 0. 25.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0739 .0018 .0000 .0000 .0000 .0998 .0000 .0000 .0555 .0000 .0055 .0240 .0000 .0444 .0092 .0185 .0000 .0277 .0000 .0055 .0000 .0000 .0000 .0166 .0000 .0240 .0000 .0000 .0555 .0111 .0185 .0000 .0000 .0000 .0055 .0000 .0333 .0721 .0333 .0055 .0000 .0000 .2662 .0000 .0000 .0111 .0000 .0000 .0185 .0166 .0000 .0462	Pollen counts converted to proportions
.32 .39 .30 .31 .29 .36 .33 .32 .31 .30 .29 .36 .29 .32 .31 .35 .34 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.29 .29 .29 .30 .30 .31 .31 .31 .31 .32 .32 .32 .33 .34 .35 .36 .36 .39	Euclidian 'distances' sorted from smallest to largest
C11 C05 C13 C03 C10 C15 C09 C18 C04 C01 C08 C14 C07 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV4. Depth 120 cm.	SITE AND SAMPLE DETAILS
0. 10. 0. 25. 61. 0. 0. 0. 0. 31. 0. 0. 41. 0. 15. 17. 0. 20. 15. 5. 0. 29. 0. 0. 0. 0. 18. 7. 0. 34. 0. 0. 41. 15. 13. 0. 0. 0. 0. 0. 42. 29. 5. 0. 0. 0. 187. 0. 0. 3. 0. 0. 8. 13. 0. 37.	Original pollen counts obtained from Appendix F
.0000 .0139 .0000 .0347 .0846 .0000 .0000 .0000 .0000 .0430 .0000 .0000 .0569 .0000 .0208 .0236 .0000 .0277 .0208 .0069 .0000 .0402 .0000 .0000 .0000 .0000 .0250 .0097 .0000 .0472 .0000 .0000 .0569 .0208 .0180 .0000 .0000 .0000 .0000 .0000 .0583 .0402 .0069 .0000 .0000 .0000 .2594 .0000 .0000 .0042 .0000 .0000 .0111 .0180 .0000 .0513	Pollen counts converted to proportions
.31 .40 .31 .32 .29 .38 .35 .35 .33 .32 .30 .38 .29 .32 .31 .35 .36 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.29 .29 .30 .31 .31 .31 .32 .32 .32 .32 .33 .35 .35 .35 .36 .38 .38 .40	Euclidian 'distances' sorted from smallest to largest
C13 C05 C11 C03 C15 C01 C10 C18 C14 C04 C09 C08 C16 C07 C17 C12 C06 C02	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 5 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 2. 0. 0. 0. 18. 80. 62. 0. 24. 0. 0. 0. 0. 2. 0. 2. 0. 46. 0. 0. 0. 0. 6. 8. 0. 114. 2. 0. 2. 4. 2. 0. 0. 0. 0. 0. 0. 0. 0. 2. 4. 0. 80. 38. 42. 0. 0. 0. 0. 0. 0. 2.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0037 .0000 .0000 .0000 .0332 .1476 .1144 .0000 .0443 .0000 .0000 .0000 .0000 .0037 .0000 .0037 .0000 .0849 .0000 .0000 .0000 .0000 .0111 .0148 .0000 .2103 .0037 .0000 .0037 .0074 .0037 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0037 .0074 .0000 .1476 .0701 .0775 .0000 .0000 .0000 .0000 .0000 .0000 .0037	Pollen counts converted to proportions
.33 .46 .23 .22 .31 .30 .26 .29 .22 .22 .24 .29 .31 .34 .35 .38 .26 .28	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .22 .22 .23 .24 .26 .26 .28 .29 .29 .30 .31 .31 .33 .34 .35 .38 .46	Euclidian 'distances' sorted from smallest to largest
C10 C04 C09 C03 C11 C17 C07 C18 C08 C12 C06 C05 C13 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 20 cm	**SITE AND SAMPLE DETAILS**
0. 0. 2. 0. 4. 0. 0. 0. 10. 68. 58. 0. 54. 0. 0. 0. 0. 2. 0. 0. 0. 78. 2. 0. 0. 0. 0. 4. 0. 132. 0. 0. 6. 0. 18. 0. 0. 0. 8. 0. 0. 0. 0. 0. 4. 0. 58. 50. 8. 0. 0. 0. 0. 0. 0. 4.	Original pollen counts obtained from Appendix F
.0000 .0000 .0035 .0000 .0070 .0000 .0000 .0000 .0175 .1193 .1018 .0000 .0947 .0000 .0000 .0000 .0000 .0035 .0000 .0000 .0000 .1368 .0035 .0000 .0000 .0000 .0000 .0070 .0000 .2316 .0000 .0000 .0105 .0000 .0316 .0000 .0000 .0000 .0140 .0000 .0000 .0000 .0000 .0000 .0070 .0000 .1018 .0877 .0140 .0000 .0000 .0000 .0000 .0000 .0000 .0070	Pollen counts converted to proportions
.35 .47 .24 .22 .34 .35 .31 .32 .25 .25 .28 .34 .33 .36 .36 .39 .31 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .24 .25 .25 .28 .30 .31 .31 .32 .33 .34 .34 .35 .35 .36 .36 .39 .47	Euclidian 'distances' sorted from smallest to largest
C04 C03 C10 C09 C11 C18 C07 C17 C08 C13 C05 C12 C06 C01 C15 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 45 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 1. 0. 0. 0. 9. 56. 47. 0. 61. 0. 0. 1. 0. 4. 0. 0. 0. 59. 0. 0. 0. 0. 1. 8. 0. 58. 0. 0. 2. 1. 8. 0. 0. 0. 2. 1. 3. 2. 0. 1. 1. 0. 41. 17. 24. 0. 0. 0. 0. 1. 0. 1.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0024 .0000 .0000 .0000 .0220 .1366 .1146 .0000 .1488 .0000 .0000 .0024 .0000 .0098 .0000 .0000 .0000 .1439 .0000 .0000 .0000 .0000 .0024 .0195 .0000 .1415 .0000 .0000 .0049 .0024 .0195 .0000 .0000 .0000 .0049 .0024 .0073 .0049 .0000 .0024 .0024 .0000 .1000 .0415 .0585 .0000 .0000 .0000 .0000 .0024 .0000 .0024	Pollen counts converted to proportions
.33 .46 .20 .20 .30 .31 .27 .28 .22 .20 .26 .31 .29 .34 .35 .38 .28 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .20 .20 .22 .26 .27 .27 .28 .28 .29 .30 .31 .31 .33 .34 .35 .38 .46	Euclidian 'distances' sorted from smallest to largest
C04 C10 C03 C09 C11 C07 C18 C17 C08 C13 C05 C12 C06 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 65 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 6. 0. 0. 0. 17. 51. 35. 0. 21. 0. 0. 5. 0. 3. 0. 0. 0. 61. 3. 0. 0. 0. 1. 3. 0. 35. 2. 0. 5. 2. 7. 0. 0. 0. 0. 1. 0. 5. 0. 8. 0. 0. 51. 29. 23. 0. 0. 0. 0. 0. 0. 5.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0158 .0000 .0000 .0000 .0449 .1346 .0923 .0000 .0554 .0000 .0000 .0132 .0000 .0079 .0000 .0000 .0000 .1609 .0079 .0000 .0000 .0000 .0026 .0079 .0000 .0923 .0053 .0000 .0132 .0053 .0185 .0000 .0000 .0000 .0000 .0026 .0000 .0132 .0000 .0211 .0000 .0000 .1346 .0765 .0607 .0000 .0000 .0000 .0000 .0000 .0000 .0132	Pollen counts converted to proportions
.30 .43 .13 .11 .27 .28 .24 .26 .18 .17 .20 .28 .27 .31 .30 .34 .25 .26	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.11 .13 .17 .18 .20 .24 .25 .26 .26 .27 .27 .28 .28 .30 .30 .31 .34 .43	Euclidian 'distances' sorted from smallest to largest
C04 C03 C10 C09 C11 C07 C17 C08 C18 C05 C13 C06 C12 C01 C15 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 85 cm	**SITE AND SAMPLE DETAILS**
0. 0. 5. 0. 9. 0. 0. 0. 10. 47. 37. 0. 42. 0. 0. 0. 0. 7. 0. 0. 0. 43. 0. 0. 0. 0. 0. 6. 0. 23. 4. 0. 0. 9. 0. 0. 0. 0. 0. 0. 4. 0. 0. 0. 0. 0. 50. 45. 5. 0. 0. 0. 0. 1. 0. 12.	Original pollen counts obtained from Appendix F
.0000 .0000 .0139 .0000 .0251 .0000 .0000 .0000 .0279 .1309 .1031 .0000 .1170 .0000 .0000 .0000 .0000 .0195 .0000 .0000 .0000 .1198 .0000 .0000 .0000 .0000 .0000 .0167 .0000 .0641 .0111 .0000 .0000 .0251 .0000 .0000 .0000 .0000 .0000 .0000 .0111 .0000 .0000 .0000 .0000 .0000 .1393 .1253 .0139 .0000 .0000 .0000 .0000 .0028 .0000 .0334	Pollen counts converted to proportions
.29 .41 .18 .16 .25 .28 .23 .25 .18 .19 .19 .27 .27 .30 .28 .33 .24 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.16 .18 .18 .19 .19 .23 .24 .25 .25 .25 .27 .27 .28 .28 .29 .30 .33 .41	Euclidian 'distances' sorted from smallest to largest
C04 C09 C03 C10 C11 C07 C17 C05 C08 C18 C13 C12 C06 C15 C01 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 105 cm	**SITE AND SAMPLE DETAILS**
0. 0. 11. 0. 10. 0. 0. 0. 3. 42. 38. 0. 19. 0. 0. 2. 0. 11. 0. 0. 0. 21. 5. 0. 0. 0. 1. 0. 0. 27. 0. 0. 2. 3. 4. 0. 0. 0. 2. 1. 5. 11. 0. 3. 0. 0. 23. 23. 0. 0. 0. 0. 0. 3. 0. 6.	Original pollen counts obtained from Appendix F
.0000 .0000 .0399 .0000 .0362 .0000 .0000 .0000 .0109 .1522 .1377 .0000 .0688 .0000 .0000 .0072 .0000 .0399 .0000 .0000 .0000 .0761 .0181 .0000 .0000 .0000 .0036 .0000 .0000 .0978 .0000 .0000 .0072 .0109 .0145 .0000 .0000 .0000 .0072 .0036 .0181 .0399 .0000 .0109 .0000 .0000 .0833 .0833 .0000 .0000 .0000 .0000 .0000 .0109 .0000 .0217	Pollen counts converted to proportions
.28 .41 .19 .18 .26 .24 .19 .21 .14 .15 .18 .23 .26 .30 .30 .32 .20 .20	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .15 .18 .18 .19 .19 .20 .20 .21 .23 .24 .26 .26 .28 .30 .30 .32 .41	Euclidian 'distances' sorted from smallest to largest
C09 C10 C11 C04 C07 C03 C17 C18 C08 C12 C06 C13 C05 C01 C15 C14 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 120 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 9. 0. 0. 0. 1. 18. 17. 0. 16. 0. 0. 0. 0. 5. 0. 0. 0. 24. 0. 0. 0. 0. 0. 0. 0. 64. 0. 0. 0. 1. 0. 0. 0. 0. 5. 2. 0. 9. 0. 0. 0. 0. 21. 21. 0. 2. 0. 0. 0. 0. 0. 13.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0395 .0000 .0000 .0000 .0044 .0789 .0746 .0000 .0702 .0000 .0000 .0000 .0000 .0219 .0000 .0000 .0000 .1053 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2807 .0000 .0000 .0000 .0044 .0000 .0000 .0000 .0000 .0219 .0088 .0000 .0395 .0000 .0000 .0000 .0000 .0921 .0921 .0000 .0088 .0000 .0000 .0000 .0000 .0000 .0570	Pollen counts converted to proportions
.35 .48 .30 .29 .35 .39 .36 .36 .31 .31 .33 .39 .35 .37 .37 .39 .36 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.29 .30 .31 .31 .31 .33 .35 .35 .35 .36 .36 .36 .37 .37 .39 .39 .39 .48	Euclidian 'distances' sorted from smallest to largest
C04 C03 C09 C10 C18 C11 C05 C13 C01 C07 C08 C17 C14 C15 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 135 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 4. 0. 0. 0. 13. 34. 21. 0. 45. 0. 0. 0. 0. 8. 0. 0. 0. 33. 0. 0. 0. 0. 2. 0. 0. 64. 4. 0. 5. 6. 0. 0. 0. 0. 3. 0. 0. 7. 0. 0. 0. 0. 59. 48. 11. 0. 0. 1. 0. 3. 0. 12.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0104 .0000 .0000 .0000 .0339 .0888 .0548 .0000 .1175 .0000 .0000 .0000 .0000 .0209 .0000 .0000 .0000 .0862 .0000 .0000 .0000 .0000 .0052 .0000 .0000 .1671 .0104 .0000 .0131 .0157 .0000 .0000 .0000 .0000 .0078 .0000 .0000 .0183 .0000 .0000 .0000 .0000 .1540 .1253 .0287 .0000 .0000 .0026 .0000 .0078 .0000 .0313	Pollen counts converted to proportions
.31 .41 .23 .22 .27 .32 .30 .30 .24 .25 .24 .33 .28 .31 .29 .35 .31 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .23 .24 .24 .25 .27 .27 .28 .29 .30 .30 .31 .31 .31 .32 .33 .35 .41	Euclidian 'distances' sorted from smallest to largest
C04 C03 C09 C11 C10 C05 C18 C13 C15 C07 C08 C17 C01 C14 C06 C12 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 150 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 10. 0. 0. 0. 5. 58. 53. 0. 16. 0. 0. 6. 0. 16. 0. 0. 0. 5. 9. 0. 3. 0. 0. 1. 0. 34. 8. 0. 0. 0. 1. 0. 0. 0. 0. 3. 2. 0. 0. 5. 0. 0. 29. 23. 6. 3. 0. 0. 0. 6. 0. 5.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0326 .0000 .0000 .0000 .0163 .1889 .1726 .0000 .0521 .0000 .0000 .0195 .0000 .0521 .0000 .0000 .0000 .0163 .0293 .0000 .0098 .0000 .0000 .0033 .0000 .1107 .0261 .0000 .0000 .0000 .0033 .0000 .0000 .0000 .0000 .0098 .0065 .0000 .0000 .0163 .0000 .0000 .0945 .0749 .0195 .0098 .0000 .0000 .0000 .0195 .0000 .0163	Pollen counts converted to proportions
.30 .42 .24 .23 .27 .22 .16 .20 .13 .16 .18 .20 .27 .31 .32 .33 .15 .19	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .15 .16 .16 .18 .19 .20 .20 .22 .23 .24 .27 .27 .30 .31 .32 .33 .42	Euclidian 'distances' sorted from smallest to largest
C09 C17 C10 C07 C11 C18 C08 C12 C06 C04 C03 C05 C13 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 170 cm	SITE AND SAMPLE DETAILS
0. 0. 1. 0. 2. 0. 0. 0. 0. 33. 33. 0. 18. 0. 0. 1. 0. 11. 0. 0. 0. 12. 3. 0. 10. 0. 0. 2. 0. 15. 5. 0. 2. 3. 0. 0. 0. 0. 0. 0. 0. 2. 0. 0. 0. 0. 46. 45. 2. 0. 0. 0. 0. 4. 0. 3.	Original pollen counts obtained from Appendix F
.0000 .0000 .0040 .0000 .0079 .0000 .0000 .0000 .0000 .1304 .1304 .0000 .0711 .0000 .0000 .0040 .0000 .0435 .0000 .0000 .0000 .0474 .0119 .0000 .0395 .0000 .0000 .0079 .0000 .0593 .0198 .0000 .0079 .0119 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0079 .0000 .0000 .0000 .0000 .1818 .1779 .0079 .0000 .0000 .0000 .0000 .0158 .0000 .0119	Pollen counts converted to proportions
.31 .38 .25 .21 .28 .28 .23 .26 .18 .22 .16 .26 .29 .32 .25 .34 .23 .26 .16 .18 .21 .22 .23 .23 .25 .25 .26 .26 .26 .28 .28 .29 .31 .32 .34 .38 C11 C09 C04 C10 C07 C17 C03 C15 C08 C18 C12 C05 C06 C13 C01 C14 C16 C02	Euclidian 'distance' of this spectrum to each of the 18 modern sites Euclidian 'distances' sorted from smallest to largest Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 190 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 3. 19. 16. 0. 23. 0. 0. 5. 0. 0. 0. 4. 0. 0. 5. 4. 3. 0. 7. 9. 0. 28. 0. 0. 0. 0. 0. 0. 0. 0. 0. 8. 0. 0. 0. 0. 0. 0. 29. 22. 7. 4. 0. 0. 0. 9. 0. 13.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0138 .0872 .0734 .0000 .1055 .0000 .0000 .0229 .0000 .0000 .0000 .0183 .0000 .0000 .0229 .0183 .0138 .0000 .0321 .0413 .0000 .1284 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0367 .0000 .0000 .0000 .0000 .0000 .0000 .1330 .1009 .0321 .0183 .0000 .0000 .0000 .0413 .0000 .0596	Pollen counts converted to proportions
.24 .42 .26 .27 .22 .29 .25 .25 .22 .22 .22 .29 .23 .26 .30 .29 .26 .24	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .22 .22 .22 .23 .24 .24 .25 .25 .26 .26 .26 .27 .29 .29 .29 .30 .42	Euclidian 'distances' sorted from smallest to largest
C05 C11 C09 C10 C13 C01 C18 C08 C07 C03 C14 C17 C04 C12 C16 C06 C15 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 205 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 0. 9. 9. 0. 18. 0. 0. 0. 0. 4. 0. 0. 0. 3. 0. 0. 0. 0. 0. 1. 0. 9. 0. 0. 0. 0. 0. 0. 4. 0. 2. 0. 0. 0. 0. 0. 0. 0. 38. 31. 7. 0. 0. 0. 0. 2. 0. 0.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0657 .0657 .0000 .1314 .0000 .0000 .0000 .0000 .0292 .0000 .0000 .0000 .0219 .0000 .0000 .0000 .0000 .0000 .0073 .0000 .0657 .0000 .0000 .0000 .0000 .0000 .0000 .0292 .0000 .0146 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2774 .2263 .0511 .0000 .0000 .0000 .0000 .0146 .0000 .0000	Pollen counts converted to proportions
.38 .39 .34 .32 .34 .40 .36 .37 .31 .35 .27 .38 .34 .37 .27 .41 .36 .36	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.27 .27 .31 .32 .34 .34 .34 .35 .36 .36 .36 .37 .37 .38 .38 .39 .40 .41	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C05 C03 C13 C10 C17 C07 C18 C08 C14 C12 C01 C02 C06 C16	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 210 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 0. 0. 0. 0. 6. 16. 10. 0. 59. 0. 0. 0. 0. 7. 0. 9. 0. 1. 0. 0. 0. 0. 4. 0. 0. 8. 0. 0. 0. 2. 0. 0. 2. 0. 0. 0. 0. 0. 0. 0. 0. 0. 151. 90. 61. 0. 0. 0. 0. 0. 0. 12.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0137 .0365 .0228 .0000 .1347 .0000 .0000 .0000 .0000 .0160 .0000 .0205 .0000 .0023 .0000 .0000 .0000 .0000 .0091 .0000 .0000 .0183 .0000 .0000 .0000 .0046 .0000 .0000 .0046 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .3447 .2055 .1393 .0000 .0000 .0000 .0000 .0000 .0000 .0274	Pollen counts converted to proportions
.43 .43 .40 .39 .37 .46 .43 .43 .39 .41 .34 .44 .39 .42 .33 .44 .43 .43	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.33 .34 .37 .39 .39 .39 .40 .41 .42 .43 .43 .43 .43 .43 .43 .44 .44 .46	Euclidian 'distances' sorted from smallest to largest
C15 C11 C05 C04 C13 C09 C03 C10 C14 C02 C07 C17 C08 C01 C18 C12 C16 C06	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 230 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 1. 9. 8. 0. 50. 0. 0. 0. 0. 5. 0. 0. 0. 3. 0. 0. 0. 0. 0. 0. 0. 15. 2. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 100. 21. 79. 0. 0. 0. 0. 2. 0. 11.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0033 .0293 .0261 .0000 .1629 .0000 .0000 .0000 .0000 .0163 .0000 .0000 .0000 .0098 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0489 .0065 .0000 .0000 .0033 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .3257 .0684 .2573 .0000 .0000 .0000 .0000 .0065 .0000 .0358	Pollen counts converted to proportions
.44 .47 .42 .43 .39 .48 .45 .46 .43 .43 .39 .47 .41 .44 .40 .47 .45 .45	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.39 .39 .40 .41 .42 .43 .43 .43 .44 .44 .45 .45 .45 .46 .47 .47 .47 .48	Euclidian 'distances' sorted from smallest to largest
C05 C11 C15 C13 C03 C10 C09 C04 C01 C14 C18 C07 C17 C08 C02 C12 C16 C06	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 235 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 0. 17. 17. 0. 30. 0. 0. 2. 0. 35. 0. 0. 0. 1. 0. 0. 0. 0. 0. 3. 0. 14. 2. 0. 0. 2. 3. 0. 0. 0. 8. 0. 0. 0. 0. 0. 0. 0. 83. 60. 23. 0. 0. 0. 0. 2. 0. 1.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0561 .0561 .0000 .0990 .0000 .0000 .0066 .0000 .1155 .0000 .0000 .0000 .0033 .0000 .0000 .0000 .0000 .0000 .0099 .0000 .0462 .0066 .0000 .0000 .0066 .0099 .0000 .0000 .0000 .0264 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2739 .1980 .0759 .0000 .0000 .0000 .0000 .0066 .0000 .0033	Pollen counts converted to proportions
.38 .30 .35 .33 .34 .39 .36 .37 .32 .35 .26 .38 .34 .37 .21 .40 .35 .33	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .26 .30 .32 .33 .33 .34 .34 .35 .35 .35 .36 .37 .37 .38 .38 .39 .40	Euclidian 'distances' sorted from smallest to largest
C15 C11 C02 C09 C18 C04 C05 C13 C03 C10 C17 C07 C08 C14 C12 C01 C06 C16	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 255 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 31. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 3. 0. 0. 12. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 116. 113. 3. 0. 0. 0. 0. 0. 0. 12.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1069 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0103 .0000 .0000 .0414 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .4000 .3897 .0103 .0000 .0000 .0000 .0000 .0000 .0000 .0414	Pollen counts converted to proportions
.55 .52 .53 .50 .50 .58 .55 .56 .51 .55 .45 .56 .52 .53 .41 .54 .56 .56	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.41 .45 .50 .50 .51 .52 .52 .53 .53 .54 .55 .55 .55 .56 .56 .56 .56 .58	Euclidian 'distances' sorted from smallest to largest
C15 C11 C04 C05 C09 C02 C13 C14 C03 C16 C01 C10 C07 C17 C08 C18 C12 C06	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 270 cm	**SITE AND SAMPLE DETAILS**
0. 0. 5. 0. 0. 0. 0. 0. 6. 33. 27. 0. 42. 0. 0. 0. 0. 19. 0. 3. 0. 0. 2. 0. 0. 0. 8. 1. 0. 5. 0. 0. 2. 0. 3. 0. 2. 0. 1. 0. 0. 0. 0. 0. 0. 0. 79. 55. 24. 0. 0. 0. 0. 0. 0. 11.	Original pollen counts obtained from Appendix F
.0000 .0000 .0152 .0000 .0000 .0000 .0000 .0000 .0183 .1006 .0823 .0000 .1280 .0000 .0000 .0000 .0000 .0579 .0000 .0091 .0000 .0000 .0061 .0000 .0000 .0000 .0244 .0030 .0000 .0152 .0000 .0000 .0061 .0000 .0091 .0000 .0061 .0000 .0030 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2409 .1677 .0732 .0000 .0000 .0000 .0000 .0000 .0000 .0335	Pollen counts converted to proportions
.34 .35 .30 .29 .27 .33 .29 .30 .26 .28 .21 .31 .30 .33 .24 .35 .29 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .24 .26 .27 .28 .29 .29 .29 .30 .30 .30 .30 .31 .33 .33 .34 .35 .35	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C05 C10 C07 C17 C04 C13 C18 C03 C08 C12 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 280 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 3. 7. 4. 0. 49. 0. 0. 0. 0. 14. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 15. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 91. 88. 3. 0. 0. 0. 0. 0. 0. 7.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0107 .0249 .0142 .0000 .1744 .0000 .0000 .0000 .0000 .0498 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0534 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .3238 .3132 .0107 .0000 .0000 .0000 .0000 .0000 .0000 .0249	Pollen counts converted to proportions
.47 .43 .45 .43 .42 .50 .47 .47 .43 .46 .38 .49 .44 .45 .33 .48 .47 .46	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.33 .38 .42 .43 .43 .43 .44 .45 .45 .46 .46 .47 .47 .47 .47 .48 .49 .50	Euclidian 'distances' sorted from smallest to largest
C15 C11 C05 C04 C09 C02 C13 C03 C14 C18 C10 C07 C01 C17 C08 C16 C12 C06	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 285 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 0. 0. 0. 0. 2. 3. 1. 0. 23. 0. 0. 2. 0. 13. 0. 7. 0. 2. 0. 0. 3. 0. 0. 6. 0. 8. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 106. 98. 7. 0. 0. 0. 0. 2. 0. 5.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0069 .0104 .0035 .0000 .0799 .0000 .0000 .0069 .0000 .0451 .0000 .0243 .0000 .0069 .0000 .0000 .0104 .0000 .0000 .0208 .0000 .0278 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .3681 .3403 .0243 .0000 .0000 .0000 .0000 .0069 .0000 .0174	Pollen counts converted to proportions
.49 .44 .47 .44 .45 .52 .50 .50 .45 .49 .39 .51 .47 .48 .34 .50 .50 .49	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.34 .39 .44 .44 .45 .45 .47 .47 .48 .49 .49 .49 .50 .50 .50 .50 .51 .52	Euclidian 'distances' sorted from smallest to largest
C15 C11 C02 C04 C05 C09 C13 C03 C14 C10 C18 C01 C17 C07 C08 C16 C12 C06	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 305 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 3. 4. 1. 0. 49. 0. 4. 0. 0. 19. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 2. 0. 0. 0. 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 68. 64. 4. 0. 0. 0. 0. 3. 0. 15.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0126 .0167 .0042 .0000 .2050 .0000 .0167 .0000 .0000 .0795 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0084 .0000 .0000 .0000 .0126 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2845 .2678 .0167 .0000 .0000 .0000 .0000 .0126 .0000 .0628	Pollen counts converted to proportions
.43 .39 .43 .42 .37 .48 .45 .45 .41 .44 .37 .47 .40 .42 .30 .44 .46 .42	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.30 .37 .37 .39 .40 .41 .42 .42 .42 .43 .43 .44 .44 .45 .45 .46 .47 .48	Euclidian 'distances' sorted from smallest to largest
C15 C11 C05 C02 C13 C09 C04 C18 C14 C03 C01 C16 C10 C08 C07 C17 C12 C06	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 330 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 0. 11. 11. 0. 60. 0. 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 24. 0. 0. 0. 0. 1. 0. 0. 0. 6. 0. 0. 0. 0. 0. 0. 0. 35. 35. 0. 0. 0. 0. 0. 0. 0. 4.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0579 .0579 .0000 .3158 .0000 .0158 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1263 .0000 .0000 .0000 .0000 .0053 .0000 .0000 .0000 .0316 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1842 .1842 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0211	Pollen counts converted to proportions
.43 .49 .41 .41 .38 .45 .42 .42 .38 .40 .37 .44 .38 .41 .38 .45 .43 .40	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.37 .38 .38 .38 .38 .40 .40 .41 .41 .41 .42 .42 .43 .43 .44 .45 .45 .49	Euclidian 'distances' sorted from smallest to largest
C11 C09 C13 C05 C15 C18 C10 C03 C04 C14 C08 C07 C17 C01 C12 C16 C06 C02	Reference numbers of the corresponding modern sites

Site: GDV1&2. Depth 360 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 0. 0. 0. 0. 0. 0. 4. 4. 0. 71. 0. 0. 0. 0. 0. 0. 8. 0. 1. 0. 0. 0. 0. 0. 0. 0. 33. 2. 0. 0. 0. 6. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 101. 75. 26. 0. 0. 0. 0. 0. 0. 7.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0118 .0118 .0000 .2101 .0000 .0000 .0000 .0000 .0000 .0000 .0237 .0000 .0030 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0976 .0059 .0000 .0000 .0000 .0178 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2988 .2219 .0769 .0000 .0000 .0000 .0000 .0000 .0000 .0207	Pollen counts converted to proportions
.43 .45 .41 .40 .39 .48 .45 .44 .40 .42 .36 .46 .40 .42 .34 .46 .45 .43	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.34 .36 .39 .40 .40 .40 .41 .42 .42 .43 .43 .44 .45 .45 .45 .46 .46 .48	Euclidian 'distances' sorted from smallest to largest
C15 C11 C05 C13 C09 C04 C03 C14 C10 C18 C01 C08 C02 C07 C17 C16 C12 C06	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 390 cm	**SITE AND SAMPLE DETAILS**
0. 0. 3. 0. 0. 0. 0. 0. 5. 30. 25. 0. 34. 0. 0. 0. 0. 3. 0. 6. 0. 0. 0. 2. 0. 0. 0. 0. 0. 30. 0. 0. 1. 0. 13. 0. 3. 0. 8. 0. 0. 0. 0. 3. 0. 0. 137. 113. 24. 0. 0. 0. 0. 0. 0. 5.	Original pollen counts obtained from Appendix F
.0000 .0000 .0067 .0000 .0000 .0000 .0000 .0000 .0112 .0674 .0562 .0000 .0764 .0000 .0000 .0000 .0000 .0067 .0000 .0135 .0000 .0000 .0000 .0045 .0000 .0000 .0000 .0000 .0000 .0674 .0000 .0000 .0022 .0000 .0292 .0000 .0067 .0000 .0180 .0000 .0000 .0000 .0000 .0067 .0000 .0000 .3079 .2539 .0539 .0000 .0000 .0000 .0000 .0000 .0000 .0112	Pollen counts converted to proportions
.41 .41 .37 .34 .35 .41 .38 .39 .33 .37 .27 .39 .37 .39 .29 .42 .37 .39	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.27 .29 .33 .34 .35 .37 .37 .37 .37 .38 .39 .39 .39 .39 .41 .41 .41 .42	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C05 C10 C03 C13 C17 C07 C08 C12 C18 C14 C06 C01 C02 C16	Reference numbers of the corresponding modern sites
Site: GDV1&2. Depth 435 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 1. 10. 9. 0. 30. 0. 0. 0. 0. 10. 0. 0. 0. 0. 0. 1. 0. 0. 0. 2. 0. 6. 0. 0. 2. 0. 7. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 64. 60. 5. 0. 0. 0. 0. 0. 0. 11.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0046 .0459 .0413 .0000 .1376 .0000 .0000 .0000 .0000 .0459 .0000 .0000 .0000 .0000 .0000 .0046 .0000 .0000 .0000 .0092 .0000 .0275 .0000 .0000 .0092 .0000 .0321 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2936 .2752 .0229 .0000 .0000 .0000 .0000 .0000 .0000 .0505	Pollen counts converted to proportions
.41 .39 .39 .37 .36 .44 .41 .41 .36 .40 .31 .42 .39 .40 .28 .41 .41 .40	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.28 .31 .36 .36 .37 .39 .39 .39 .40 .40 .40 .41 .41 .41 .41 .41 .42 .44	Euclidian 'distances' sorted from smallest to largest
C15 C11 C05 C09 C04 C13 C03 C02 C10 C18 C14 C07 C17 C08 C16 C01 C12 C06	Reference numbers of the corresponding modern sites

Site: KFN Depth 10 cm	SITE AND SAMPLE DETAILS
5. 4. 2. 15. 9. 7. 0. 13. 33. 256. 223. 0. 10. 0. 0. 13. 0. 3. 0. 13. 0. 76. 11. 8. 0. 0. 14. 21. 0. 24. 1. 8. 4. 6. 15. 0. 0. 0. 23. 0. 0. 0. 0. 44. 4. 0. 49. 28. 21. 1. 0. 0. 0. 3. 13. 12.	Original pollen counts obtained from Appendix F
.0050 .0040 .0020 .0151 .0091 .0071 .0000 .0131 .0333 .2581 .2248 .0000 .0101 .0000 .0000 .0131 .0000 .0030 .0000 .0131 .0000 .0766 .0111 .0081 .0000 .0000 .0141 .0212 .0000 .0242 .0010 .0081 .0040 .0060 .0151 .0000 .0000 .0000 .0232 .0000 .0000 .0000 .0000 .0444 .0040 .0000 .0494 .0282 .0212 .0010 .0000 .0000 .0000 .0030 .0131 .0121	Pollen counts converted to proportions
.35 .51 .24 .24 .31 .21 .13 .18 .15 .14 .22 .17 .32 .36 .41 .36 .13 .26	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .13 .14 .15 .17 .18 .21 .22 .24 .24 .26 .31 .32 .35 .36 .36 .41 .51	Euclidian 'distances' sorted from smallest to largest
C07 C17 C10 C09 C12 C08 C06 C11 C04 C03 C18 C05 C13 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 20 cm	**SITE AND SAMPLE DETAILS**
2. 13. 3. 7. 4. 8. 0. 8. 14. 131. 117. 0. 12. 0. 0. 8. 0. 0. 0. 16. 0. 45. 7. 11. 0. 0. 23. 12. 0. 40. 0. 13. 7. 8. 21. 0. 0. 0. 21. 2. 0. 0. 0. 15. 2. 0. 45. 37. 8. 0. 0. 0. 0. 4. 13. 10.	Original pollen counts obtained from Appendix F
.0029 .0189 .0044 .0102 .0058 .0116 .0000 .0116 .0204 .1907 .1703 .0000 .0175 .0000 .0000 .0116 .0000 .0000 .0000 .0233 .0000 .0655 .0102 .0160 .0000 .0000 .0335 .0175 .0000 .0582 .0000 .0189 .0102 .0116 .0306 .0000 .0000 .0000 .0306 .0029 .0000 .0000 .0000 .0218 .0029 .0000 .0655 .0539 .0116 .0000 .0000 .0000 .0000 .0058 .0189 .0146	Pollen counts converted to proportions
.29 .46 .19 .19 .26 .19 .11 .14 .09 .08 .15 .15 .25 .30 .34 .31 .12 .20	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.08 .09 .11 .12 .14 .15 .15 .19 .19 .19 .20 .25 .26 .29 .30 .31 .34 .46	Euclidian 'distances' sorted from smallest to largest
C10 C09 C07 C17 C08 C12 C11 C03 C04 C06 C18 C13 C05 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 26 cm	**SITE AND SAMPLE DETAILS**
0. 17. 2. 0. 2. 8. 0. 4. 3. 170. 167. 0. 15. 0. 0. 7. 0. 0. 0. 10. 0. 67. 7. 5. 0. 0. 7. 8. 0. 24. 0. 7. 4. 3. 13. 0. 0. 0. 13. 0. 0. 0. 0. 5. 0. 0. 82. 71. 11. 0. 0. 0. 0. 5. 20. 16.	Original pollen counts obtained from Appendix F
.0000 .0220 .0026 .0000 .0026 .0103 .0000 .0052 .0039 .2199 .2160 .0000 .0194 .0000 .0000 .0091 .0000 .0000 .0000 .0129 .0000 .0867 .0091 .0065 .0000 .0000 .0091 .0103 .0000 .0310 .0000 .0091 .0052 .0039 .0168 .0000 .0000 .0000 .0168 .0000 .0000 .0000 .0000 .0065 .0000 .0000 .1061 .0918 .0142 .0000 .0000 .0000 .0000 .0065 .0259 .0207	Pollen counts converted to proportions
.33 .47 .22 .19 .29 .22 .13 .18 .10 .14 .16 .16 .31 .34 .35 .34 .13 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.10 .13 .13 .14 .16 .16 .18 .19 .22 .22 .25 .29 .31 .33 .34 .34 .35 .47	Euclidian 'distances' sorted from smallest to largest
C09 C07 C17 C10 C11 C12 C08 C04 C03 C06 C18 C05 C13 C01 C16 C14 C15 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 34 cm	SITE AND SAMPLE DETAILS
0. 8. 1. 4. 6. 6. 0. 4. 16. 103. 87. 0. 15. 0. 0. 8. 0. 5. 0. 5. 0. 137. 4. 13. 0. 0. 12. 6. 0. 23. 0. 11. 1. 5. 5. 0. 0. 0. 7. 4. 0. 0. 0. 12. 0. 0. 46. 37. 9. 0. 0. 0. 0. 3. 6. 3.	Original pollen counts obtained from Appendix F
.0000 .0131 .0016 .0065 .0098 .0098 .0000 .0065 .0261 .1683 .1422 .0000 .0245 .0000 .0000 .0131 .0000 .0082 .0000 .0082 .0000 .2239 .0065 .0212 .0000 .0000 .0196 .0098 .0000 .0376 .0000 .0180 .0016 .0082 .0082 .0000 .0000 .0000 .0114 .0065 .0000 .0000 .0000 .0196 .0000 .0000 .0752 .0605 .0147 .0000 .0000 .0000 .0000 .0049 .0098 .0049	Pollen counts converted to proportions
.33 .48 .15 .12 .31 .29 .24 .26 .20 .17 .24 .27 .31 .35 .36 .37 .25 .28	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.12 .15 .17 .20 .24 .24 .25 .26 .27 .28 .29 .31 .31 .33 .35 .36 .37 .48	Euclidian 'distances' sorted from smallest to largest
C04 C03 C10 C09 C07 C11 C17 C08 C12 C18 C06 C13 C05 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 42 cm	**SITE AND SAMPLE DETAILS**
0. 14. 0. 6. 0. 0. 0. 1. 27. 100. 73. 0. 17. 0. 0. 7. 0. 14. 0. 14. 0. 113. 0. 7. 3. 0. 9. 8. 0. 3. 0. 6. 0. 1. 2. 0. 0. 0. 19. 0. 0. 0. 0. 3. 0. 0. 28. 25. 3. 5. 0. 0. 0. 2. 11. 34.	Original pollen counts obtained from Appendix F
.0000 .0252 .0000 .0108 .0000 .0000 .0000 .0018 .0486 .1802 .1315 .0000 .0306 .0000 .0000 .0126 .0000 .0252 .0000 .0252 .0000 .2036 .0000 .0126 .0054 .0000 .0162 .0144 .0000 .0054 .0000 .0108 .0000 .0018 .0036 .0000 .0000 .0000 .0342 .0000 .0000 .0000 .0000 .0054 .0000 .0000 .0505 .0450 .0054 .0090 .0000 .0000 .0000 .0036 .0198 .0613	Pollen counts converted to proportions
.31 .47 .15 .15 .27 .26 .22 .23 .20 .17 .24 .26 .30 .33 .35 .32 .24 .26 .15 .15 .17 .20 .22 .23 .24 .24 .26 .26 .26 .27 .30 .31 .32 .33 .35 .47 C04 C03 C10 C09 C07 C08 C17 C11 C18 C06 C12 C05 C13 C01 C16 C14 C15 C02	Euclidian 'distance' of this spectrum to each of the 18 modern sites Euclidian 'distances' sorted from smallest to largest Reference numbers of the corresponding modern sites
Site: KFN Depth 47 cm	**SITE AND SAMPLE DETAILS**
0. 2. 2. 10. 0. 0. 0. 4. 10. 68. 58. 0. 14. 0. 0. 0. 0. 17. 0. 15. 0. 74. 2. 3. 3. 0. 11. 20. 0. 9. 0. 7. 0. 0. 3. 0. 0. 5. 10. 5. 2. 0. 0. 7. 0. 0. 69. 59. 10. 2. 0. 0. 0. 2. 0. 27.	Original pollen counts obtained from Appendix F
.0000 .0038 .0038 .0189 .0000 .0000 .0000 .0075 .0189 .1283 .1094 .0000 .0264 .0000 .0000 .0000 .0000 .0321 .0000 .0283 .0000 .1396 .0038 .0057 .0057 .0000 .0208 .0377 .0000 .0170 .0000 .0132 .0000 .0000 .0057 .0000 .0000 .0094 .0189 .0094 .0038 .0000 .0000 .0132 .0000 .0000 .1302 .1113 .0189 .0038 .0000 .0000 .0000 .0038 .0000 .0509	Pollen counts converted to proportions
.26 .39 .15 .12 .23 .26 .20 .21 .17 .16 .16 .24 .26 .29 .26 .29 .22 .23	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.12 .15 .16 .16 .17 .20 .21 .22 .23 .23 .24 .26 .26 .26 .26 .29 .29 .39	Euclidian 'distances' sorted from smallest to largest
C04 C03 C11 C10 C09 C07 C08 C17 C18 C05 C12 C13 C06 C15 C01 C14 C16 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 55 cm	SITE AND SAMPLE DETAILS
0. 5. 0. 3. 0. 0. 0. 0. 32. 78. 46. 0. 20. 0. 0. 0. 0. 27. 0. 12. 0. 63. 4. 2. 4. 0. 2. 13. 0. 8. 5. 12. 3. 3. 6. 0. 0. 1. 14. 2. 3. 0. 7. 9. 0. 0. 106. 71. 35. 4. 2. 0. 0. 14. 3. 49.	Original pollen counts obtained from Appendix F
.0000 .0075 .0000 .0045 .0000 .0000 .0000 .0000 .0479 .1168 .0689 .0000 .0299 .0000 .0000 .0000 .0000 .0404 .0000 .0180 .0000 .0943 .0060 .0030 .0060 .0000 .0030 .0195 .0000 .0120 .0075 .0180 .0045 .0045 .0090 .0000 .0000 .0015 .0210 .0030 .0045 .0000 .0105 .0135 .0000 .0000 .1587 .1063 .0524 .0060 .0030 .0000 .0000 .0210 .0045 .0734	Pollen counts converted to proportions
.24 .36 .16 .16 .18 .24 .21 .22 .19 .18 .17 .26 .24 .27 .23 .26 .23 .22	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.16 .16 .17 .18 .18 .19 .21 .22 .22 .23 .23 .24 .24 .24 .26 .26 .27 .36	Euclidian 'distances' sorted from smallest to largest
C03 C04 C11 C10 C05 C09 C07 C08 C18 C17 C15 C13 C01 C06 C12 C16 C14 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 65 cm	**SITE AND SAMPLE DETAILS**
0. 13. 0. 6. 2. 4. 0. 0. 33. 72. 39. 0. 6. 0. 0. 3. 0. 18. 0. 13. 0. 56. 0. 11. 2. 0. 6. 8. 0. 6. 0. 9. 2. 2. 7. 0. 0. 2. 9. 0. 5. 0. 2. 2. 0. 0. 76. 55. 21. 2. 3. 0. 0. 2. 0. 29.	Original pollen counts obtained from Appendix F
.0000 .0247 .0000 .0114 .0038 .0076 .0000 .0000 .0627 .1369 .0741 .0000 .0114 .0000 .0000 .0057 .0000 .0342 .0000 .0247 .0000 .1065 .0000 .0209 .0038 .0000 .0114 .0152 .0000 .0114 .0000 .0171 .0038 .0038 .0133 .0000 .0000 .0038 .0171 .0000 .0095 .0000 .0038 .0038 .0000 .0000 .1445 .1046 .0399 .0038 .0057 .0000 .0000 .0038 .0000 .0551	Pollen counts converted to proportions
.26 .38 .14 .13 .19 .23 .20 .20 .16 .16 .15 .24 .24 .28 .24 .28 .21 .22	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .14 .15 .16 .16 .19 .20 .20 .21 .22 .23 .24 .24 .24 .26 .28 .28 .38	Euclidian 'distances' sorted from smallest to largest
C04 C03 C11 C10 C09 C05 C07 C08 C17 C18 C06 C12 C13 C15 C01 C16 C14 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 75 cm	**SITE AND SAMPLE DETAILS**
0. 17. 0. 6. 0. 0. 0. 1. 13. 56. 43. 0. 22. 0. 0. 4. 0. 9. 0. 5. 0. 16. 1. 0. 0. 0. 6. 13. 0. 3. 0. 4. 0. 5. 12. 0. 0. 0. 6. 3. 0. 0. 0. 4. 0. 0. 74. 59. 15. 0. 0. 0. 0. 0. 0. 7.	Original pollen counts obtained from Appendix F
.0000 .0421 .0000 .0149 .0000 .0000 .0000 .0025 .0322 .1386 .1064 .0000 .0545 .0000 .0000 .0099 .0000 .0223 .0000 .0124 .0000 .0396 .0025 .0000 .0000 .0000 .0149 .0322 .0000 .0074 .0000 .0099 .0000 .0124 .0297 .0000 .0000 .0000 .0149 .0074 .0000 .0000 .0000 .0099 .0000 .0000 .1832 .1460 .0371 .0000 .0000 .0000 .0000 .0000 .0000 .0173	Pollen counts converted to proportions
.29 .37 .21 .20 .23 .25 .19 .21 .16 .19 .12 .23 .25 .29 .23 .31 .20 .24	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.12 .16 .19 .19 .20 .20 .21 .21 .23 .23 .23 .24 .25 .25 .29 .29 .31 .37	Euclidian 'distances' sorted from smallest to largest
C11 C09 C10 C07 C17 C04 C08 C03 C12 C15 C05 C18 C13 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 84 cm	SITE AND SAMPLE DETAILS
0. 5. 0. 0. 0. 0. 0. 0. 25. 54. 29. 0. 39. 0. 0. 3. 0. 6. 0. 8. 0. 16. 6. 0. 0. 0. 0. 11. 0. 13. 0. 7. 0. 0. 83. 0. 0. 0. 7. 0. 0. 0. 0. 0. 0. 0. 116. 86. 30. 0. 0. 0. 0. 0. 0. 9.	Original pollen counts obtained from Appendix F
.0000 .0090 .0000 .0000 .0000 .0000 .0000 .0000 .0452 .0976 .0524 .0000 .0705 .0000 .0000 .0054 .0000 .0108 .0000 .0145 .0000 .0289 .0108 .0000 .0000 .0000 .0000 .0199 .0000 .0235 .0000 .0127 .0000 .0000 .1501 .0000 .0000 .0000 .0127 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2098 .1555 .0542 .0000 .0000 .0000 .0000 .0000 .0000 .0163	Pollen counts converted to proportions
.34 .37 .26 .25 .28 .32 .30 .30 .24 .26 .18 .32 .29 .33 .24 .35 .30 .31	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.18 .24 .24 .25 .26 .26 .28 .29 .30 .30 .30 .31 .32 .32 .33 .34 .35 .37	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C10 C03 C05 C13 C07 C17 C08 C18 C06 C12 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 95 cm	**SITE AND SAMPLE DETAILS**
0. 8. 0. 0. 0. 0. 0. 2. 14. 65. 51. 0. 10. 0. 0. 4. 0. 5. 0. 9. 0. 19. 4. 4. 0. 0. 11. 2. 0. 7. 0. 1. 0. 4. 67. 0. 0. 0. 11. 2. 0. 0. 0. 0. 0. 0. 122. 109. 13. 0. 0. 0. 0. 9. 5. 25.	Original pollen counts obtained from Appendix F
.0000 .0137 .0000 .0000 .0000 .0000 .0000 .0034 .0240 .1115 .0875 .0000 .0172 .0000 .0000 .0069 .0000 .0086 .0000 .0154 .0000 .0326 .0069 .0069 .0000 .0000 .0189 .0034 .0000 .0120 .0000 .0017 .0000 .0069 .1149 .0000 .0000 .0000 .0189 .0034 .0000 .0000 .0000 .0000 .0000 .0000 .2093 .1870 .0223 .0000 .0000 .0000 .0000 .0154 .0086 .0429	Pollen counts converted to proportions
.32 .38 .26 .23 .26 .30 .26 .28 .22 .24 .14 .28 .30 .32 .23 .32 .27 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .22 .23 .23 .24 .26 .26 .26 .27 .28 .28 .30 .30 .30 .32 .32 .32 .38	Euclidian 'distances' sorted from smallest to largest
C11 C09 C04 C15 C10 C03 C05 C07 C17 C08 C12 C13 C06 C18 C01 C16 C14 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 105 cm	**SITE AND SAMPLE DETAILS**
0. 9. 0. 7. 5. 0. 0. 0. 10. 74. 64. 0. 27. 0. 0. 7. 0. 0. 0. 14. 0. 33. 0. 3. 0. 0. 13. 17. 0. 12. 0. 3. 0. 3. 59. 0. 0. 2. 12. 0. 0. 0. 0. 3. 0. 0. 106. 91. 15. 0. 0. 0. 0. 4. 4. 11.	Original pollen counts obtained from Appendix F
.0000 .0148 .0000 .0115 .0082 .0000 .0000 .0000 .0164 .1217 .1053 .0000 .0444 .0000 .0000 .0115 .0000 .0000 .0000 .0230 .0000 .0543 .0000 .0049 .0000 .0000 .0214 .0280 .0000 .0197 .0000 .0049 .0000 .0049 .0970 .0000 .0000 .0033 .0197 .0000 .0000 .0000 .0000 .0049 .0000 .0000 .1743 .1497 .0247 .0000 .0000 .0000 .0000 .0066 .0066 .0181	Pollen counts converted to proportions
.30 .39 .22 .19 .25 .27 .22 .23 .16 .19 .10 .24 .26 .30 .24 .31 .22 .26	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.10 .16 .19 .19 .22 .22 .22 .23 .24 .24 .25 .26 .26 .27 .30 .30 .31 .39	Euclidian 'distances' sorted from smallest to largest
C11 C09 C10 C04 C03 C07 C17 C08 C15 C12 C05 C13 C18 C06 C01 C14 C16 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 118 cm	SITE AND SAMPLE DETAILS
0. 4. 0. 0. 3. 0. 0. 0. 0. 78. 78. 0. 16. 0. 0. 2. 0. 3. 0. 6. 0. 41. 7. 0. 0. 0. 4. 13. 0. 23. 0. 0. 3. 3. 35. 0. 0. 0. 7. 0. 11. 0. 0. 0. 0. 0. 158. 143. 15. 0. 1. 0. 0. 3. 0. 11.	Original pollen counts obtained from Appendix F
.0000 .0060 .0000 .0000 .0045 .0000 .0000 .0000 .0000 .1168 .1168 .0000 .0240 .0000 .0000 .0030 .0000 .0045 .0000 .0090 .0000 .0614 .0105 .0000 .0000 .0000 .0060 .0195 .0000 .0344 .0000 .0000 .0045 .0045 .0524 .0000 .0000 .0000 .0105 .0000 .0165 .0000 .0000 .0000 .0000 .0000 .2365 .2141 .0225 .0000 .0015 .0000 .0000 .0045 .0000 .0165	Pollen counts converted to proportions
.35 .40 .27 .22 .30 .32 .27 .30 .22 .26 .17 .29 .32 .35 .26 .36 .27 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.17 .22 .22 .26 .26 .27 .27 .27 .29 .30 .30 .32 .32 .32 .35 .35 .36 .40	Euclidian 'distances' sorted from smallest to largest
C11 C09 C04 C15 C10 C17 C07 C03 C12 C08 C05 C13 C18 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 128 cm	**SITE AND SAMPLE DETAILS**
0. 7. 2. 7. 0. 0. 0. 0. 8. 51. 43. 0. 24. 0. 0. 3. 0. 0. 0. 11. 0. 31. 2. 0. 4. 0. 14. 5. 0. 3. 4. 3. 0. 12. 13. 0. 0. 3. 8. 5. 0. 0. 0. 0. 0. 0. 81. 74. 7. 5. 5. 0. 0. 2. 3. 25.	Original pollen counts obtained from Appendix F
.0000 .0151 .0043 .0151 .0000 .0000 .0000 .0000 .0172 .1097 .0925 .0000 .0516 .0000 .0000 .0065 .0000 .0000 .0000 .0237 .0000 .0667 .0043 .0000 .0086 .0000 .0301 .0108 .0000 .0065 .0086 .0065 .0000 .0258 .0280 .0000 .0000 .0065 .0172 .0108 .0000 .0000 .0000 .0000 .0000 .0000 .1742 .1591 .0151 .0108 .0108 .0000 .0000 .0043 .0065 .0538	Pollen counts converted to proportions
.27 .39 .21 .19 .22 .27 .21 .23 .18 .20 .14 .24 .25 .28 .24 .28 .23 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .18 .19 .20 .21 .21 .22 .23 .23 .24 .24 .25 .25 .27 .27 .28 .28 .39	Euclidian 'distances' sorted from smallest to largest
C11 C09 C04 C10 C03 C07 C05 C08 C17 C15 C12 C13 C18 C06 C01 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 133 cm	**SITE AND SAMPLE DETAILS**
0. 6. 0. 8. 7. 0. 0. 0. 4. 76. 72. 0. 17. 0. 0. 4. 0. 0. 0. 4. 0. 71. 6. 0. 2. 0. 4. 4. 0. 12. 8. 1. 0. 0. 12. 0. 0. 0. 7. 12. 0. 0. 8. 7. 0. 0. 69. 61. 8. 3. 6. 0. 0. 0. 0. 28.	Original pollen counts obtained from Appendix F
.0000 .0114 .0000 .0152 .0133 .0000 .0000 .0000 .0076 .1442 .1366 .0000 .0323 .0000 .0000 .0076 .0000 .0000 .0000 .0076 .0000 .1347 .0114 .0000 .0038 .0000 .0076 .0076 .0000 .0228 .0152 .0019 .0000 .0000 .0228 .0000 .0000 .0000 .0133 .0228 .0000 .0000 .0152 .0133 .0000 .0000 .1309 .1157 .0152 .0057 .0114 .0000 .0000 .0000 .0000 .0531	Pollen counts converted to proportions
.28 .43 .16 .12 .24 .26 .19 .21 .14 .16 .16 .23 .26 .30 .29 .29 .21 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.12 .14 .16 .16 .16 .19 .21 .21 .23 .24 .25 .26 .26 .28 .29 .29 .30 .43	Euclidian 'distances' sorted from smallest to largest
C04 C09 C10 C11 C03 C07 C17 C08 C12 C05 C18 C06 C13 C01 C15 C16 C14 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 140 cm	SITE AND SAMPLE DETAILS
0. 0. 4. 4. 1. 0. 0. 0. 12. 83. 71. 0. 7. 0. 0. 3. 0. 7. 0. 7. 0. 55. 21. 0. 5. 0. 10. 17. 0. 21. 6. 1. 0. 0. 10. 0. 0. 0. 17. 1. 0. 0. 2. 3. 0. 0. 107. 87. 20. 4. 8. 0. 0. 2. 5. 3.	Original pollen counts obtained from Appendix F
.0000 .0000 .0066 .0066 .0017 .0000 .0000 .0000 .0199 .1374 .1175 .0000 .0116 .0000 .0000 .0050 .0000 .0116 .0000 .0116 .0000 .0911 .0348 .0000 .0083 .0000 .0166 .0281 .0000 .0348 .0099 .0017 .0000 .0000 .0166 .0000 .0000 .0000 .0281 .0017 .0000 .0000 .0033 .0050 .0000 .0000 .1772 .1440 .0331 .0066 .0132 .0000 .0000 .0033 .0083 .0050	Pollen counts converted to proportions
.30 .40 .18 .15 .26 .26 .20 .23 .15 .18 .13 .23 .26 .30 .26 .33 .21 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .15 .15 .18 .18 .20 .21 .23 .23 .25 .26 .26 .26 .26 .30 .30 .33 .40	Euclidian 'distances' sorted from smallest to largest
C11 C04 C09 C10 C03 C07 C17 C08 C12 C18 C06 C15 C13 C05 C01 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 150 cm	**SITE AND SAMPLE DETAILS**
0. 12. 3. 7. 9. 0. 0. 0. 32. 67. 35. 0. 27. 0. 0. 9. 0. 17. 0. 0. 0. 105. 21. 0. 7. 0. 17. 4. 0. 11. 25. 0. 8. 7. 22. 0. 0. 7. 14. 2. 8. 0. 5. 6. 0. 0. 121. 79. 42. 2. 3. 0. 0. 1. 26. 0.	Original pollen counts obtained from Appendix F
.0000 .0158 .0039 .0092 .0118 .0000 .0000 .0000 .0420 .0880 .0460 .0000 .0355 .0000 .0000 .0118 .0000 .0223 .0000 .0000 .0000 .1380 .0276 .0000 .0092 .0000 .0223 .0053 .0000 .0145 .0329 .0000 .0105 .0092 .0289 .0000 .0000 .0092 .0184 .0026 .0105 .0000 .0066 .0079 .0000 .0000 .1590 .1038 .0552 .0026 .0039 .0000 .0000 .0013 .0342 .0000	Pollen counts converted to proportions
.29 .37 .14 .15 .26 .29 .27 .27 .22 .20 .19 .30 .24 .29 .24 .34 .27 .26	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .15 .19 .20 .22 .24 .24 .26 .26 .27 .27 .27 .29 .29 .29 .30 .34 .37	Euclidian 'distances' sorted from smallest to largest
C03 C04 C11 C10 C09 C15 C13 C05 C18 C07 C08 C17 C01 C14 C06 C12 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 160 cm	**SITE AND SAMPLE DETAILS**
0. 11. 4. 6. 5. 0. 0. 4. 45. 78. 33. 0. 27. 0. 0. 13. 0. 21. 0. 4. 0. 73. 3. 3. 0. 0. 13. 3. 0. 8. 12. 3. 3. 3. 5. 0. 0. 0. 12. 0. 0. 0. 3. 1. 0. 0. 112. 45. 67. 2. 0. 0. 0. 1. 17. 6.	Original pollen counts obtained from Appendix F
.0000 .0170 .0062 .0093 .0077 .0000 .0000 .0062 .0697 .1207 .0511 .0000 .0418 .0000 .0000 .0201 .0000 .0325 .0000 .0062 .0000 .1130 .0046 .0046 .0000 .0000 .0201 .0046 .0000 .0124 .0186 .0046 .0046 .0046 .0077 .0000 .0000 .0000 .0186 .0000 .0000 .0000 .0046 .0015 .0000 .0000 .1734 .0697 .1037 .0031 .0000 .0000 .0000 .0015 .0263 .0093	Pollen counts converted to proportions
.29 .38 .15 .17 .24 .26 .24 .25 .21 .19 .20 .28 .24 .29 .26 .33 .25 .26	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.15 .17 .19 .20 .21 .24 .24 .24 .25 .25 .26 .26 .26 .28 .29 .29 .33 .38	Euclidian 'distances' sorted from smallest to largest
C03 C04 C10 C11 C09 C05 C13 C07 C08 C17 C18 C06 C15 C12 C01 C14 C16 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 173 cm	SITE AND SAMPLE DETAILS
0. 7. 6. 0. 6. 3. 0. 0. 29. 69. 40. 0. 9. 0. 0. 16. 0. 36. 0. 3. 0. 22. 13. 11. 0. 0. 31. 21. 0. 3. 0. 0. 6. 2. 0. 0. 0. 0. 16. 0. 2. 0. 0. 4. 0. 0. 89. 43. 46. 0. 1. 0. 0. 3. 4. 5.	Original pollen counts obtained from Appendix F
.0000 .0128 .0110 .0000 .0110 .0055 .0000 .0000 .0531 .1264 .0733 .0000 .0165 .0000 .0000 .0293 .0000 .0659 .0000 .0055 .0000 .0403 .0238 .0201 .0000 .0000 .0568 .0385 .0000 .0055 .0000 .0000 .0110 .0037 .0000 .0000 .0000 .0000 .0293 .0000 .0037 .0000 .0000 .0073 .0000 .0000 .1630 .0788 .0842 .0000 .0018 .0000 .0000 .0055 .0073 .0092	Pollen counts converted to proportions
.27 .34 .19 .22 .22 .23 .20 .21 .19 .18 .17 .23 .22 .28 .24 .31 .21 .21	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.17 .18 .19 .19 .20 .21 .21 .21 .22 .22 .22 .23 .23 .24 .27 .28 .31 .34	Euclidian 'distances' sorted from smallest to largest
C11 C10 C09 C03 C07 C17 C08 C18 C04 C05 C13 C12 C06 C15 C01 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 179 cm	**SITE AND SAMPLE DETAILS**
0. 5. 3. 7. 4. 9. 0. 8. 57. 95. 38. 0. 7. 0. 0. 5. 0. 40. 0. 2. 0. 20. 4. 6. 0. 0. 16. 26. 0. 13. 0. 0. 1. 2. 4. 0. 0. 0. 19. 0. 0. 0. 0. 5. 0. 0. 171. 80. 91. 0. 0. 0. 0. 5. 11. 8.	Original pollen counts obtained from Appendix F
.0000 .0066 .0039 .0092 .0052 .0118 .0000 .0105 .0748 .1247 .0499 .0000 .0092 .0000 .0000 .0066 .0000 .0525 .0000 .0026 .0000 .0262 .0052 .0079 .0000 .0000 .0210 .0341 .0000 .0171 .0000 .0000 .0013 .0026 .0052 .0000 .0000 .0000 .0249 .0000 .0000 .0000 .0000 .0066 .0000 .0000 .2244 .1050 .1194 .0000 .0000 .0000 .0000 .0066 .0144 .0105	Pollen counts converted to proportions
.31 .36 .23 .24 .25 .27 .26 .27 .24 .24 .20 .28 .27 .31 .25 .34 .26 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .23 .24 .24 .24 .25 .25 .26 .26 .27 .27 .27 .27 .28 .31 .31 .34 .36	Euclidian 'distances' sorted from smallest to largest
C11 C03 C09 C10 C04 C05 C15 C17 C07 C08 C06 C13 C18 C12 C01 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 187 cm	**SITE AND SAMPLE DETAILS**
0. 13. 1. 5. 5. 7. 0. 5. 49. 96. 47. 0. 7. 0. 0. 6. 0. 57. 0. 5. 0. 8. 0. 6. 1. 0. 22. 31. 0. 21. 0. 0. 2. 1. 0. 0. 0. 6. 25. 0. 4. 0. 3. 4. 0. 0. 176. 86. 90. 0. 0. 0. 0. 1. 8. 10.	Original pollen counts obtained from Appendix F
.0000 .0161 .0012 .0062 .0062 .0087 .0000 .0062 .0606 .1188 .0582 .0000 .0087 .0000 .0000 .0074 .0000 .0705 .0000 .0062 .0000 .0099 .0000 .0074 .0012 .0000 .0272 .0384 .0000 .0260 .0000 .0000 .0025 .0012 .0000 .0000 .0000 .0074 .0309 .0000 .0050 .0000 .0037 .0050 .0000 .0000 .2178 .1064 .1114 .0000 .0000 .0000 .0000 .0012 .0099 .0124	Pollen counts converted to proportions
.31 .33 .24 .25 .25 .27 .25 .26 .23 .24 .19 .27 .26 .31 .23 .34 .25 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .23 .23 .24 .24 .25 .25 .25 .25 .25 .26 .26 .27 .27 .31 .31 .33 .34	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C10 C03 C17 C05 C07 C18 C04 C08 C13 C06 C12 C01 C14 C02 C16	Reference numbers of the corresponding modern sites

Site: KFN Depth 200 cm	SITE AND SAMPLE DETAILS
0. 7. 1. 5. 0. 5. 0. 6. 50. 119. 69. 0. 12. 0. 0. 1. 0. 88. 0. 2. 0. 4. 0. 15. 0. 0. 8. 32. 0. 19. 2. 0. 1. 1. 8. 0. 0. 13. 20. 1. 0. 0. 0. 0. 0. 0. 234. 140. 94. 0. 0. 0. 0. 0. 0. 5.	Original pollen counts obtained from Appendix F
.0000 .0073 .0010 .0052 .0000 .0052 .0000 .0062 .0520 .1237 .0717 .0000 .0125 .0000 .0000 .0010 .0000 .0915 .0000 .0021 .0000 .0042 .0000 .0156 .0000 .0000 .0083 .0333 .0000 .0198 .0021 .0000 .0010 .0010 .0083 .0000 .0000 .0135 .0208 .0010 .0000 .0000 .0000 .0000 .0000 .0000 .2432 .1455 .0977 .0000 .0000 .0000 .0000 .0000 .0000 .0052	Pollen counts converted to proportions
.34 .32 .27 .27 .28 .29 .27 .28 .25 .27 .20 .29 .30 .33 .22 .36 .26 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .22 .25 .26 .27 .27 .27 .27 .27 .28 .28 .29 .29 .30 .32 .33 .34 .36	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C17 C04 C10 C07 C18 C03 C05 C08 C06 C12 C13 C02 C14 C01 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 210 cm	**SITE AND SAMPLE DETAILS**
0. 5. 0. 5. 3. 0. 0. 8. 67. 101. 34. 0. 9. 0. 0. 4. 0. 66. 0. 0. 0. 14. 2. 3. 3. 0. 5. 17. 0. 9. 0. 0. 1. 2. 2. 0. 0. 10. 9. 0. 1. 0. 7. 6. 0. 0. 246. 114. 132. 1. 0. 0. 0. 5. 0. 6.	Original pollen counts obtained from Appendix F
.0000 .0056 .0000 .0056 .0033 .0000 .0000 .0089 .0747 .1126 .0379 .0000 .0100 .0000 .0000 .0045 .0000 .0736 .0000 .0000 .0000 .0156 .0022 .0033 .0033 .0000 .0056 .0190 .0000 .0100 .0000 .0000 .0011 .0022 .0022 .0000 .0000 .0111 .0100 .0000 .0011 .0000 .0078 .0067 .0000 .0000 .2742 .1271 .1472 .0011 .0000 .0000 .0000 .0056 .0000 .0067	Pollen counts converted to proportions
.36 .35 .29 .29 .30 .32 .32 .33 .29 .30 .25 .34 .32 .35 .26 .39 .31 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.25 .26 .29 .29 .29 .30 .30 .31 .32 .32 .32 .32 .33 .34 .35 .35 .36 .39	Euclidian 'distances' sorted from smallest to largest
C11 C15 C03 C04 C09 C05 C10 C17 C07 C13 C18 C06 C08 C12 C02 C14 C01 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 225 cm	**SITE AND SAMPLE DETAILS**
0. 3. 0. 2. 0. 4. 0. 7. 23. 65. 42. 0. 22. 0. 0. 5. 0. 56. 0. 0. 0. 6. 0. 6. 0. 0. 11. 17. 0. 23. 0. 0. 0. 0. 11. 0. 0. 14. 8. 0. 0. 0. 0. 0. 0. 0. 192. 159. 33. 0. 0. 0. 0. 0. 2. 13.	Original pollen counts obtained from Appendix F
.0000 .0041 .0000 .0028 .0000 .0055 .0000 .0097 .0318 .0898 .0580 .0000 .0304 .0000 .0000 .0069 .0000 .0773 .0000 .0000 .0000 .0083 .0000 .0083 .0000 .0000 .0152 .0235 .0000 .0318 .0000 .0000 .0000 .0000 .0152 .0000 .0000 .0193 .0110 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2652 .2196 .0456 .0000 .0000 .0000 .0000 .0000 .0028 .0180	Pollen counts converted to proportions
.36 .33 .31 .29 .31 .35 .32 .33 .28 .32 .22 .34 .33 .35 .21 .37 .32 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .22 .28 .29 .31 .31 .32 .32 .32 .32 .33 .33 .33 .34 .35 .35 .36 .37	Euclidian 'distances' sorted from smallest to largest
C15 C11 C09 C04 C05 C03 C10 C17 C18 C07 C13 C02 C08 C12 C06 C14 C01 C16	Reference numbers of the corresponding modern sites

Site: KFN Depth 245 cm	SITE AND SAMPLE DETAILS
0. 7. 0. 3. 0. 7. 0. 0. 12. 57. 45. 0. 11. 0. 0. 2. 0. 29. 0. 4. 0. 23. 7. 11. 0. 0. 3. 16. 0. 7. 0. 0. 2. 3. 0. 0. 0. 6. 7. 0. 0. 0. 3. 3. 0. 0. 150. 119. 31. 2. 1. 0. 0. 3. 0. 23.	Original pollen counts obtained from Appendix F
.0000 .0117 .0000 .0050 .0000 .0117 .0000 .0000 .0201 .0955 .0754 .0000 .0184 .0000 .0000 .0034 .0000 .0486 .0000 .0067 .0000 .0385 .0117 .0184 .0000 .0000 .0050 .0268 .0000 .0117 .0000 .0000 .0034 .0050 .0000 .0000 .0000 .0101 .0117 .0000 .0000 .0000 .0050 .0050 .0000 .0000 .2513 .1993 .0519 .0034 .0017 .0000 .0000 .0050 .0000 .0385	Pollen counts converted to proportions
.33 .35 .28 .25 .27 .32 .29 .30 .25 .28 .20 .31 .31 .33 .22 .34 .29 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .22 .25 .25 .27 .28 .28 .29 .29 .30 .30 .31 .31 .32 .33 .33 .34 .35	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C05 C03 C10 C07 C17 C08 C18 C13 C12 C06 C01 C14 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 262 cm	**SITE AND SAMPLE DETAILS**
0. 3. 3. 0. 0. 3. 0. 7. 7. 29. 22. 0. 7. 0. 0. 3. 0. 46. 0. 3. 0. 9. 1. 6. 1. 0. 6. 8. 0. 15. 0. 0. 2. 3. 3. 0. 0. 0. 10. 0. 0. 0. 1. 4. 0. 0. 151. 137. 14. 1. 0. 0. 0. 2. 0. 7.	Original pollen counts obtained from Appendix F
.0000 .0058 .0058 .0000 .0000 .0058 .0000 .0136 .0136 .0564 .0428 .0000 .0136 .0000 .0000 .0058 .0000 .0895 .0000 .0058 .0000 .0175 .0019 .0117 .0019 .0000 .0117 .0156 .0000 .0292 .0000 .0000 .0039 .0058 .0058 .0000 .0000 .0000 .0195 .0000 .0000 .0000 .0019 .0078 .0000 .0000 .2938 .2665 .0272 .0019 .0000 .0000 .0000 .0039 .0000 .0136	Pollen counts converted to proportions
.40 .34 .37 .34 .36 .41 .38 .39 .34 .38 .28 .39 .37 .39 .23 .41 .38 .37	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.23 .28 .34 .34 .34 .36 .37 .37 .37 .38 .38 .38 .39 .39 .39 .40 .41 .41	Euclidian 'distances' sorted from smallest to largest
C15 C11 C04 C09 C02 C05 C03 C18 C13 C10 C17 C07 C08 C14 C12 C01 C06 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 285 cm	**SITE AND SAMPLE DETAILS**
0. 1. 3. 2. 2. 2. 0. 1. 12. 68. 56. 0. 12. 0. 0. 3. 0. 13. 0. 0. 0. 27. 4. 22. 0. 0. 7. 21. 0. 11. 2. 0. 5. 4. 15. 0. 0. 2. 6. 2. 0. 0. 0. 3. 0. 0. 190. 170. 20. 1. 0. 0. 0. 0. 4. 5.	Original pollen counts obtained from Appendix F
.0000 .0014 .0043 .0029 .0029 .0029 .0000 .0014 .0172 .0977 .0805 .0000 .0172 .0000 .0000 .0043 .0000 .0187 .0000 .0000 .0000 .0388 .0057 .0316 .0000 .0000 .0101 .0302 .0000 .0158 .0029 .0000 .0072 .0057 .0216 .0000 .0000 .0029 .0086 .0029 .0000 .0000 .0000 .0043 .0000 .0000 .2730 .2443 .0287 .0014 .0000 .0000 .0000 .0000 .0057 .0072	Pollen counts converted to proportions
.37 .39 .31 .27 .32 .36 .32 .33 .28 .32 .22 .34 .34 .36 .26 .38 .32 .35	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .26 .27 .28 .31 .32 .32 .32 .32 .33 .34 .34 .35 .36 .36 .37 .38 .39	Euclidian 'distances' sorted from smallest to largest
C11 C15 C04 C09 C03 C10 C17 C07 C05 C08 C12 C13 C18 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 300 cm	SITE AND SAMPLE DETAILS
0. 2. 2. 3. 0. 0. 0. 2. 3. 42. 39. 0. 12. 0. 0. 0. 0. 26. 0. 0. 0. 11. 3. 9. 0. 0. 9. 12. 0. 12. 6. 2. 1. 3. 8. 0. 0. 0. 7. 0. 0. 0. 0. 5. 0. 0. 167. 155. 12. 0. 2. 0. 0. 1. 0. 13.	Original pollen counts obtained from Appendix F
.0000 .0035 .0035 .0053 .0000 .0000 .0000 .0035 .0053 .0738 .0685 .0000 .0211 .0000 .0000 .0000 .0000 .0457 .0000 .0000 .0000 .0193 .0053 .0158 .0000 .0000 .0158 .0211 .0000 .0211 .0105 .0035 .0018 .0053 .0141 .0000 .0000 .0000 .0123 .0000 .0000 .0000 .0000 .0088 .0000 .0000 .2935 .2724 .0211 .0000 .0035 .0000 .0000 .0018 .0000 .0228	Pollen counts converted to proportions
.40 .38 .36 .32 .35 .39 .36 .37 .32 .36 .26 .37 .37 .39 .26 .40 .36 .38	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.26 .26 .32 .32 .35 .36 .36 .36 .36 .37 .37 .37 .38 .38 .39 .39 .40 .40	Euclidian 'distances' sorted from smallest to largest
C15 C11 C09 C04 C05 C03 C17 C10 C07 C13 C08 C12 C18 C02 C14 C06 C01 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 322 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 3. 2. 0. 1. 4. 29. 25. 0. 7. 0. 0. 3. 0. 16. 0. 0. 0. 7. 12. 5. 0. 0. 3. 7. 0. 11. 0. 0. 1. 1. 0. 0. 0. 0. 8. 1. 1. 0. 1. 1. 0. 0. 107. 101. 6. 0. 0. 0. 0. 0. 0. 6.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0000 .0081 .0054 .0000 .0027 .0108 .0786 .0678 .0000 .0190 .0000 .0000 .0081 .0000 .0434 .0000 .0000 .0000 .0190 .0325 .0136 .0000 .0000 .0081 .0190 .0000 .0298 .0000 .0000 .0027 .0027 .0000 .0000 .0000 .0000 .0217 .0027 .0027 .0000 .0027 .0027 .0000 .0000 .2900 .2737 .0163 .0000 .0000 .0000 .0000 .0000 .0000 .0163	Pollen counts converted to proportions
.40 .39 .35 .32 .35 .39 .36 .37 .32 .36 .26 .37 .37 .39 .26 .40 .36 .38	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.26 .26 .32 .32 .35 .35 .36 .36 .36 .37 .37 .37 .38 .39 .39 .39 .40 .40	Euclidian 'distances' sorted from smallest to largest
C15 C11 C09 C04 C05 C03 C17 C10 C07 C13 C08 C12 C18 C14 C02 C06 C01 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 350 cm	**SITE AND SAMPLE DETAILS**
0. 2. 2. 0. 0. 2. 0. 4. 7. 28. 21. 0. 30. 0. 0. 0. 0. 5. 0. 0. 0. 3. 0. 0. 0. 0. 2. 9. 0. 8. 0. 0. 0. 0. 2. 0. 0. 7. 6. 0. 0. 0. 0. 0. 0. 0. 165. 137. 28. 0. 0. 0. 0. 1. 0. 4.	Original pollen counts obtained from Appendix F
.0000 .0042 .0042 .0000 .0000 .0042 .0000 .0085 .0148 .0592 .0444 .0000 .0634 .0000 .0000 .0000 .0000 .0106 .0000 .0000 .0000 .0063 .0000 .0000 .0000 .0000 .0042 .0190 .0000 .0169 .0000 .0000 .0000 .0000 .0042 .0000 .0000 .0148 .0127 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .3488 .2896 .0592 .0000 .0000 .0000 .0000 .0021 .0000 .0085	Pollen counts converted to proportions
.45 .43 .41 .38 .40 .45 .42 .43 .38 .42 .32 .43 .41 .43 .32 .46 .42 .44	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.32 .32 .38 .38 .40 .41 .41 .42 .42 .42 .43 .43 .43 .43 .44 .45 .45 .46	Euclidian 'distances' sorted from smallest to largest
C15 C11 C04 C09 C05 C03 C13 C17 C10 C07 C02 C12 C14 C08 C18 C01 C06 C16	Reference numbers of the corresponding modern sites

Site: KFN Depth 376 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 2. 0. 0. 0. 3. 11. 44. 33. 0. 13. 0. 0. 0. 0. 43. 0. 0. 0. 5. 3. 0. 0. 0. 5. 1. 0. 24. 0. 0. 3. 0. 0. 0. 0. 0. 1. 0. 0. 0. 2. 2. 0. 0. 94. 69. 25. 1. 1. 0. 0. 3. 3. 6.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0050 .0000 .0000 .0000 .0076 .0277 .1108 .0831 .0000 .0327 .0000 .0000 .0000 .0000 .1083 .0000 .0000 .0000 .0126 .0076 .0000 .0000 .0000 .0126 .0025 .0000 .0605 .0000 .0000 .0076 .0000 .0000 .0000 .0000 .0000 .0025 .0000 .0000 .0000 .0050 .0050 .0000 .0000 .2368 .1738 .0630 .0025 .0025 .0000 .0000 .0076 .0076 .0151	Pollen counts converted to proportions
.34 .31 .28 .27 .29 .31 .28 .30 .25 .27 .20 .30 .30 .33 .20 .36 .28 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .20 .25 .27 .27 .27 .28 .28 .28 .29 .30 .30 .30 .31 .31 .33 .34 .36	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C18 C10 C17 C07 C03 C05 C08 C12 C13 C02 C06 C14 C01 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 400 cm	**SITE AND SAMPLE DETAILS**
0. 1. 0. 0. 0. 2. 0. 7. 18. 35. 17. 0. 7. 0. 0. 6. 0. 77. 0. 0. 0. 13. 0. 0. 0. 0. 3. 7. 0. 21. 0. 0. 2. 2. 5. 0. 0. 17. 4. 0. 0. 0. 0. 0. 0. 0. 154. 99. 55. 0. 0. 0. 0. 0. 0. 11.	Original pollen counts obtained from Appendix F
.0000 .0018 .0000 .0000 .0000 .0036 .0000 .0124 .0320 .0622 .0302 .0000 .0124 .0000 .0000 .0107 .0000 .1368 .0000 .0000 .0000 .0231 .0000 .0000 .0000 .0000 .0053 .0124 .0000 .0373 .0000 .0000 .0036 .0036 .0089 .0000 .0000 .0302 .0071 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2735 .1758 .0977 .0000 .0000 .0000 .0000 .0000 .0000 .0195	Pollen counts converted to proportions
.37 .27 .33 .32 .32 .38 .36 .37 .32 .34 .26 .38 .34 .37 .19 .39 .35 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .26 .27 .32 .32 .32 .32 .33 .34 .34 .35 .36 .37 .37 .37 .38 .38 .39	Euclidian 'distances' sorted from smallest to largest
C15 C11 C02 C04 C18 C09 C05 C03 C13 C10 C17 C07 C08 C14 C01 C12 C06 C16	Reference numbers of the corresponding modern sites
Site: KFN Depth 424 cm	**SITE AND SAMPLE DETAILS**
0. 2. 1. 2. 2. 0. 0. 0. 15. 33. 18. 0. 6. 0. 0. 4. 0. 32. 0. 4. 0. 5. 3. 1. 0. 0. 3. 6. 0. 19. 1. 0. 1. 7. 2. 0. 0. 1. 8. 0. 0. 0. 2. 1. 0. 0. 104. 65. 39. 0. 0. 0. 0. 1. 0. 5.	Original pollen counts obtained from Appendix F
.0000 .0051 .0025 .0051 .0051 .0000 .0000 .0000 .0382 .0840 .0458 .0000 .0153 .0000 .0000 .0102 .0000 .0814 .0000 .0102 .0000 .0127 .0076 .0025 .0000 .0000 .0076 .0153 .0000 .0483 .0025 .0000 .0025 .0178 .0051 .0000 .0000 .0025 .0204 .0000 .0000 .0000 .0051 .0025 .0000 .0000 .2646 .1654 .0992 .0000 .0000 .0000 .0000 .0025 .0000 .0127	Pollen counts converted to proportions
.34 .32 .29 .28 .29 .34 .31 .32 .28 .30 .23 .33 .31 .34 .22 .37 .31 .30	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .23 .28 .28 .29 .29 .30 .30 .31 .31 .31 .32 .32 .33 .34 .34 .34 .37	Euclidian 'distances' sorted from smallest to largest
C15 C11 C09 C04 C05 C03 C10 C18 C13 C17 C07 C08 C02 C12 C06 C14 C01 C16	Reference numbers of the corresponding modern sites

Site: KFN Depth 450 cm	SITE AND SAMPLE DETAILS
0. 0. 2. 3. 0. 3. 0. 0. 5. 44. 39. 0. 33. 0. 0. 2. 0. 6. 0. 0. 0. 5. 0. 4. 0. 0. 0. 2. 0. 5. 0. 0. 3. 1. 3. 0. 0. 8. 1. 0. 0. 0. 1. 2. 0. 0. 150. 134. 16. 0. 0. 0. 0. 0. 0. 9.	Original pollen counts obtained from Appendix F
.0000 .0000 .0042 .0062 .0000 .0062 .0000 .0000 .0104 .0915 .0811 .0000 .0686 .0000 .0000 .0042 .0000 .0125 .0000 .0000 .0000 .0104 .0000 .0083 .0000 .0000 .0000 .0042 .0000 .0104 .0000 .0000 .0062 .0021 .0062 .0000 .0000 .0166 .0021 .0000 .0000 .0000 .0021 .0042 .0000 .0000 .3119 .2786 .0333 .0000 .0000 .0000 .0000 .0000 .0000 .0187	Pollen counts converted to proportions
.42 .42 .37 .34 .36 .40 .37 .38 .33 .37 .28 .38 .38 .40 .30 .42 .37 .40	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.28 .30 .33 .34 .36 .37 .37 .37 .37 .38 .38 .38 .40 .40 .40 .42 .42 .42	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C05 C17 C07 C10 C03 C12 C08 C13 C18 C14 C06 C16 C01 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 475 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 1. 2. 2. 0. 1. 6. 36. 30. 0. 12. 0. 0. 3. 0. 11. 0. 3. 0. 11. 5. 0. 0. 0. 3. 2. 0. 31. 0. 0. 0. 2. 0. 0. 0. 4. 6. 1. 0. 0. 0. 3. 0. 0. 104. 90. 14. 2. 0. 0. 0. 0. 5. 5.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0025 .0051 .0051 .0000 .0025 .0152 .0911 .0759 .0000 .0304 .0000 .0000 .0076 .0000 .0278 .0000 .0076 .0000 .0278 .0127 .0000 .0000 .0000 .0076 .0051 .0000 .0785 .0000 .0000 .0000 .0051 .0000 .0000 .0000 .0101 .0152 .0025 .0000 .0000 .0000 .0076 .0000 .0000 .2633 .2278 .0354 .0051 .0000 .0000 .0000 .0000 .0127 .0127	Pollen counts converted to proportions
.36 .38 .31 .27 .32 .35 .32 .33 .27 .31 .22 .33 .33 .35 .25 .38 .31 .33	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .25 .27 .27 .31 .31 .31 .32 .32 .33 .33 .33 .33 .35 .35 .36 .38 .38	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C04 C03 C10 C17 C05 C07 C13 C08 C18 C12 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: KFN Depth 495 cm	**SITE AND SAMPLE DETAILS**
0. 3. 1. 3. 3. 0. 0. 0. 12. 81. 69. 0. 21. 0. 0. 4. 0. 8. 0. 8. 0. 13. 5. 5. 0. 0. 6. 6. 0. 33. 2. 1. 1. 2. 5. 0. 0. 5. 2. 2. 0. 0. 0. 4. 0. 0. 192. 155. 37. 3. 0. 0. 0. 1. 14. 13.	Original pollen counts obtained from Appendix F
.0000 .0042 .0014 .0042 .0042 .0000 .0000 .0000 .0167 .1125 .0958 .0000 .0292 .0000 .0000 .0056 .0000 .0111 .0000 .0111 .0000 .0181 .0069 .0069 .0000 .0000 .0083 .0083 .0000 .0458 .0028 .0014 .0014 .0028 .0069 .0000 .0000 .0069 .0028 .0028 .0000 .0000 .0000 .0056 .0000 .0000 .2667 .2153 .0514 .0042 .0000 .0000 .0000 .0014 .0194 .0181	Pollen counts converted to proportions
.36 .40 .30 .27 .30 .33 .29 .31 .25 .29 .20 .31 .32 .35 .27 .36 .29 .33	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .25 .27 .27 .29 .29 .29 .30 .30 .31 .31 .32 .33 .33 .35 .36 .36 .40	Euclidian 'distances' sorted from smallest to largest
C11 C09 C15 C04 C17 C10 C07 C03 C05 C12 C08 C13 C06 C18 C14 C01 C16 C02	Reference numbers of the corresponding modern sites

Site: KFN Depth 512 cm	SITE AND SAMPLE DETAILS
0. 4. 3. 7. 4. 3. 0. 2. 11. 83. 72. 0. 8. 0. 0. 8. 0. 13. 0. 7. 0. 14. 6. 4. 0. 0. 5. 11. 0. 12. 1. 0. 2. 3. 1. 0. 0. 0. 3. 3. 0. 0. 4. 5. 0. 0. 177. 132. 45. 0. 2. 0. 0. 2. 8. 15.	Original pollen counts obtained from Appendix F
.0000 .0059 .0044 .0103 .0059 .0044 .0000 .0029 .0162 .1221 .1059 .0000 .0118 .0000 .0000 .0118 .0000 .0191 .0000 .0103 .0000 .0206 .0088 .0059 .0000 .0000 .0074 .0162 .0000 .0176 .0015 .0000 .0029 .0044 .0015 .0000 .0000 .0000 .0044 .0044 .0000 .0000 .0059 .0074 .0000 .0000 .2603 .1941 .0662 .0000 .0029 .0000 .0000 .0029 .0118 .0221	Pollen counts converted to proportions
.34 .39 .29 .26 .29 .31 .27 .29 .23 .27 .19 .29 .31 .34 .26 .35 .27 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .23 .26 .26 .27 .27 .27 .29 .29 .29 .29 .31 .31 .32 .34 .34 .35 .39	Euclidian 'distances' sorted from smallest to largest
C11 C09 C04 C15 C17 C07 C10 C03 C12 C05 C08 C13 C06 C18 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 15 cm	**SITE AND SAMPLE DETAILS**
6. 15. 0. 22. 0. 2. 0. 0. 6. 104. 98. 0. 12. 0. 14. 19. 0. 3. 0. 31. 7. 0. 0. 25. 0. 0. 12. 15. 0. 18. 3. 0. 0. 0. 0. 0. 0. 0. 18. 0. 0. 0. 0. 3. 0. 0. 51. 30. 21. 0. 0. 0. 0. 0. 0. 13.	Original pollen counts obtained from Appendix F
.0109 .0274 .0000 .0401 .0000 .0036 .0000 .0000 .0109 .1898 .1788 .0000 .0219 .0000 .0255 .0347 .0000 .0055 .0000 .0566 .0128 .0000 .0000 .0456 .0000 .0000 .0219 .0274 .0000 .0328 .0055 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0328 .0000 .0000 .0000 .0000 .0055 .0000 .0000 .0931 .0547 .0383 .0000 .0000 .0000 .0000 .0000 .0000 .0237	Pollen counts converted to proportions
.29 .45 .25 .25 .24 .20 .09 .10 .12 .13 .16 .14 .24 .29 .34 .30 .09 .19	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.09 .09 .10 .12 .13 .14 .16 .19 .20 .24 .24 .25 .25 .29 .29 .30 .34 .45	Euclidian 'distances' sorted from smallest to largest
C07 C17 C08 C09 C10 C12 C11 C18 C06 C13 C05 C03 C04 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 31 cm	**SITE AND SAMPLE DETAILS**
6. 11. 2. 9. 0. 19. 0. 0. 29. 166. 137. 0. 8. 0. 0. 20. 0. 23. 0. 37. 0. 0. 0. 23. 0. 0. 6. 41. 0. 49. 0. 0. 1. 0. 0. 0. 0. 3. 25. 0. 0. 0. 0. 0. 1. 0. 43. 8. 35. 0. 4. 0. 0. 0. 0. 5.	Original pollen counts obtained from Appendix F
.0084 .0155 .0028 .0127 .0000 .0267 .0000 .0000 .0408 .2335 .1927 .0000 .0113 .0000 .0000 .0281 .0000 .0323 .0000 .0520 .0000 .0000 .0000 .0323 .0000 .0000 .0084 .0577 .0000 .0689 .0000 .0000 .0014 .0000 .0000 .0000 .0000 .0042 .0352 .0000 .0000 .0000 .0000 .0000 .0014 .0000 .0605 .0113 .0492 .0000 .0056 .0000 .0000 .0000 .0000 .0070	Pollen counts converted to proportions
.33 .47 .26 .28 .29 .19 .12 .14 .16 .16 .21 .17 .29 .34 .39 .35 .11 .20	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.11 .12 .14 .16 .16 .17 .19 .20 .21 .26 .28 .29 .29 .33 .34 .35 .39 .47	Euclidian 'distances' sorted from smallest to largest
C17 C07 C08 C10 C09 C12 C06 C18 C11 C03 C04 C05 C13 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites

Site: MBS Depth 47 cm	SITE AND SAMPLE DETAILS
17. 23. 3. 14. 0. 6. 0. 7. 13. 100. 87. 0. 22. 0. 2. 31. 0. 7. 0. 21. 1. 0. 0. 8. 0. 0. 16. 12. 0. 8. 2. 0. 0. 1. 0. 0. 3. 1. 15. 5. 0. 0. 0. 1. 3. 0. 67. 13. 54. 0. 0. 0. 0. 0. 0. 15.	Original pollen counts obtained from Appendix F
.0294 .0398 .0052 .0242 .0000 .0104 .0000 .0121 .0225 .1730 .1505 .0000 .0381 .0000 .0035 .0536 .0000 .0121 .0000 .0363 .0017 .0000 .0000 .0138 .0000 .0000 .0277 .0208 .0000 .0138 .0035 .0000 .0000 .0017 .0000 .0000 .0052 .0017 .0260 .0087 .0000 .0000 .0000 .0017 .0052 .0000 .1159 .0225 .0934 .0000 .0000 .0000 .0000 .0000 .0000 .0260	Pollen counts converted to proportions
.28 .43 .24 .26 .23 .21 .13 .14 .15 .15 .18 .17 .23 .29 .33 .29 .13 .20	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .13 .14 .15 .15 .17 .18 .20 .21 .23 .23 .24 .26 .28 .29 .29 .33 .43	Euclidian 'distances' sorted from smallest to largest
C07 C17 C08 C10 C09 C12 C11 C18 C06 C05 C13 C03 C04 C01 C14 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 55 cm	**SITE AND SAMPLE DETAILS**
8. 25. 0. 7. 0. 3. 0. 1. 68. 145. 77. 0. 8. 0. 0. 28. 0. 11. 0. 17. 1. 0. 0. 15. 0. 0. 7. 5. 0. 12. 0. 0. 0. 0. 0. 0. 0. 0. 7. 0. 0. 0. 0. 0. 0. 0. 61. 17. 44. 0. 20. 0. 0. 0. 0. 3.	Original pollen counts obtained from Appendix F
.0136 .0424 .0000 .0119 .0000 .0051 .0000 .0017 .1153 .2458 .1305 .0000 .0136 .0000 .0000 .0475 .0000 .0186 .0000 .0288 .0017 .0000 .0000 .0254 .0000 .0000 .0119 .0085 .0000 .0203 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0119 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1034 .0288 .0746 .0000 .0339 .0000 .0000 .0000 .0000 .0051	Pollen counts converted to proportions
.33 .46 .23 .26 .25 .14 .15 .16 .16 .16 .21 .19 .27 .32 .37 .34 .14 .23	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .14 .15 .16 .16 .16 .19 .21 .23 .23 .25 .26 .27 .32 .33 .34 .37 .46	Euclidian 'distances' sorted from smallest to largest
C17 C06 C07 C10 C09 C08 C12 C11 C18 C03 C05 C04 C13 C14 C01 C16 C15 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 60 cm	**SITE AND SAMPLE DETAILS**
1. 6. 0. 5. 0. 0. 0. 0. 75. 116. 41. 0. 13. 0. 5. 44. 0. 5. 0. 11. 3. 5. 0. 7. 0. 0. 0. 14. 0. 66. 0. 0. 0. 0. 1. 0. 8. 0. 16. 0. 0. 0. 0. 0. 0. 0. 102. 62. 40. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.0015 .0093 .0000 .0077 .0000 .0000 .0000 .0000 .1161 .1796 .0635 .0000 .0201 .0000 .0077 .0681 .0000 .0077 .0000 .0170 .0046 .0077 .0000 .0108 .0000 .0000 .0000 .0217 .0000 .1022 .0000 .0000 .0000 .0000 .0015 .0000 .0124 .0000 .0248 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1579 .0960 .0619 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.31 .43 .21 .23 .24 .20 .22 .22 .17 .19 .20 .26 .25 .29 .31 .33 .21 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.17 .19 .20 .20 .21 .21 .22 .22 .23 .24 .25 .25 .26 .29 .31 .31 .33 .43	Euclidian 'distances' sorted from smallest to largest
C09 C10 C11 C06 C17 C03 C07 C08 C04 C05 C18 C13 C12 C14 C01 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: MBS Depth 70 cm	SITE AND SAMPLE DETAILS
0. 0. 1. 25. 0. 0. 0. 0. 35. 66. 31. 0. 20. 0. 0. 17. 0. 10. 0. 28. 0. 14. 0. 43. 0. 0. 2. 1. 0. 178. 0. 0. 0. 7. 0. 0. 0. 0. 19. 0. 0. 0. 0. 0. 0. 0. 162. 101. 61. 0. 0. 0. 0. 0. 0. 49.	Original pollen counts obtained from Appendix F
.0000 .0000 .0011 .0287 .0000 .0000 .0000 .0000 .0402 .0759 .0356 .0000 .0230 .0000 .0000 .0195 .0000 .0115 .0000 .0322 .0000 .0161 .0000 .0494 .0000 .0000 .0023 .0011 .0000 .2046 .0000 .0000 .0000 .0080 .0000 .0000 .0000 .0000 .0218 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1862 .1161 .0701 .0000 .0000 .0000 .0000 .0000 .0000 .0563	Pollen counts converted to proportions
.31 .42 .29 .29 .27 .34 .32 .31 .28 .29 .27 .35 .30 .32 .31 .33 .32 .29	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.27 .27 .28 .29 .29 .29 .29 .30 .31 .31 .31 .32 .32 .32 .33 .34 .35 .42	Euclidian 'distances' sorted from smallest to largest
C11 C05 C09 C10 C04 C18 C03 C13 C08 C15 C01 C07 C14 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 80 cm	**SITE AND SAMPLE DETAILS**
3. 12. 0. 14. 0. 17. 0. 0. 30. 89. 59. 0. 24. 0. 0. 9. 0. 28. 0. 43. 0. 8. 0. 14. 0. 0. 18. 3. 0. 43. 0. 0. 2. 0. 8. 0. 6. 0. 37. 0. 0. 0. 0. 0. 0. 0. 134. 113. 21. 0. 0. 0. 0. 0. 0. 13.	Original pollen counts obtained from Appendix F
.0040 .0160 .0000 .0187 .0000 .0227 .0000 .0000 .0401 .1190 .0789 .0000 .0321 .0000 .0000 .0120 .0000 .0374 .0000 .0575 .0000 .0107 .0000 .0187 .0000 .0000 .0241 .0040 .0000 .0575 .0000 .0000 .0027 .0000 .0107 .0000 .0080 .0000 .0495 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1791 .1511 .0281 .0000 .0000 .0000 .0000 .0000 .0000 .0174	Pollen counts converted to proportions
.29 .36 .24 .23 .23 .25 .21 .21 .18 .21 .13 .23 .25 .28 .22 .31 .22 .21	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .18 .21 .21 .21 .21 .22 .22 .23 .23 .23 .24 .25 .25 .28 .29 .31 .36	Euclidian 'distances' sorted from smallest to largest
C11 C09 C10 C08 C07 C18 C17 C15 C04 C05 C12 C03 C13 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 90 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 19. 0. 0. 0. 0. 29. 140. 111. 0. 19. 0. 0. 6. 0. 14. 0. 32. 0. 11. 0. 8. 0. 0. 52. 5. 0. 327. 0. 0. 0. 3. 4. 0. 0. 0. 45. 0. 0. 0. 0. 1. 0. 0. 79. 57. 22. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0193 .0000 .0000 .0000 .0000 .0295 .1423 .1128 .0000 .0193 .0000 .0000 .0061 .0000 .0142 .0000 .0325 .0000 .0112 .0000 .0081 .0000 .0000 .0528 .0051 .0000 .3323 .0000 .0000 .0000 .0030 .0041 .0000 .0000 .0000 .0457 .0000 .0000 .0000 .0000 .0010 .0000 .0000 .0803 .0579 .0224 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.40 .52 .36 .35 .39 .36 .34 .35 .31 .31 .34 .36 .38 .40 .43 .44 .34 .32	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.31 .31 .32 .34 .34 .34 .35 .35 .36 .36 .36 .38 .39 .40 .40 .43 .44 .52	Euclidian 'distances' sorted from smallest to largest
C09 C10 C18 C11 C17 C07 C08 C04 C03 C12 C06 C13 C05 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: MBS Depth 105 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 8. 0. 6. 0. 0. 25. 122. 97. 0. 10. 0. 0. 3. 0. 34. 0. 45. 0. 1. 0. 12. 0. 0. 9. 18. 0. 167. 0. 0. 1. 6. 16. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 49. 38. 11. 0. 0. 0. 0. 0. 0. 13.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0112 .0000 .0084 .0000 .0000 .0350 .1709 .1359 .0000 .0140 .0000 .0000 .0042 .0000 .0476 .0000 .0630 .0000 .0014 .0000 .0168 .0000 .0000 .0126 .0252 .0000 .2339 .0000 .0000 .0014 .0084 .0224 .0000 .0000 .0000 .0322 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0686 .0532 .0154 .0000 .0000 .0000 .0000 .0000 .0000 .0182	Pollen counts converted to proportions
.34 .46 .29 .29 .32 .28 .25 .25 .23 .23 .25 .28 .32 .35 .37 .37 .24 .22	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.22 .23 .23 .24 .25 .25 .25 .28 .28 .29 .29 .32 .32 .34 .35 .37 .37 .46	Euclidian 'distances' sorted from smallest to largest
C18 C09 C10 C17 C07 C08 C11 C12 C06 C04 C03 C13 C05 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 115 cm	**SITE AND SAMPLE DETAILS**
0. 48. 3. 26. 0. 8. 0. 0. 7. 88. 81. 0. 7. 0. 5. 29. 0. 2. 0. 16. 0. 21. 0. 16. 0. 0. 5. 24. 0. 122. 0. 0. 0. 0. 13. 0. 24. 0. 13. 0. 0. 0. 0. 7. 0. 0. 126. 103. 23. 0. 3. 0. 0. 0. 0. 19.	Original pollen counts obtained from Appendix F
.0000 .0572 .0036 .0310 .0000 .0095 .0000 .0000 .0083 .1049 .0965 .0000 .0083 .0000 .0060 .0346 .0000 .0024 .0000 .0191 .0000 .0250 .0000 .0191 .0000 .0000 .0060 .0286 .0000 .1454 .0000 .0000 .0000 .0000 .0155 .0000 .0286 .0000 .0155 .0000 .0000 .0000 .0000 .0083 .0000 .0000 .1502 .1228 .0274 .0000 .0036 .0000 .0000 .0000 .0000 .0226	Pollen counts converted to proportions
.28 .41 .24 .23 .26 .29 .23 .23 .18 .21 .19 .27 .25 .29 .27 .31 .23 .23	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.18 .19 .21 .23 .23 .23 .23 .23 .24 .25 .26 .27 .27 .28 .29 .29 .31 .41	Euclidian 'distances' sorted from smallest to largest
C09 C11 C10 C17 C04 C07 C18 C08 C03 C13 C05 C12 C15 C01 C14 C06 C16 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 120 cm	**SITE AND SAMPLE DETAILS**
0. 27. 5. 29. 0. 0. 0. 4. 12. 44. 32. 0. 11. 0. 12. 18. 0. 23. 0. 14. 0. 27. 0. 65. 0. 0. 10. 13. 0. 43. 2. 0. 5. 2. 43. 0. 9. 0. 8. 0. 0. 3. 0. 0. 0. 0. 141. 128. 13. 3. 0. 0. 0. 0. 0. 30.	Original pollen counts obtained from Appendix F
.0000 .0348 .0064 .0374 .0000 .0000 .0000 .0052 .0155 .0567 .0412 .0000 .0142 .0000 .0155 .0232 .0000 .0296 .0000 .0180 .0000 .0348 .0000 .0838 .0000 .0000 .0129 .0168 .0000 .0554 .0026 .0000 .0064 .0026 .0554 .0000 .0116 .0000 .0103 .0000 .0000 .0039 .0000 .0000 .0000 .0000 .1817 .1649 .0168 .0039 .0000 .0000 .0000 .0000 .0000 .0387	Pollen counts converted to proportions
.28 .35 .26 .25 .24 .32 .28 .27 .24 .26 .20 .32 .26 .28 .21 .30 .29 .26	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .21 .24 .24 .25 .26 .26 .26 .26 .27 .28 .28 .28 .29 .30 .32 .32 .35	Euclidian 'distances' sorted from smallest to largest
C11 C15 C09 C05 C04 C13 C10 C03 C18 C08 C14 C01 C07 C17 C16 C12 C06 C02	Reference numbers of the corresponding modern sites

Site: MBS Depth 130 cm	SITE AND SAMPLE DETAILS
0. 15. 0. 22. 0. 0. 0. 0. 17. 47. 30. 0. 30. 0. 3. 20. 0. 24. 0. 4. 0. 52. 0. 54. 0. 0. 5. 8. 0. 29. 0. 0. 12. 0. 31. 0. 13. 0. 12. 2. 0. 1. 0. 0. 0. 0. 168. 137. 31. 3. 0. 0. 0. 0. 0. 37.	Original pollen counts obtained from Appendix F
.0000 .0186 .0000 .0273 .0000 .0000 .0000 .0000 .0211 .0582 .0372 .0000 .0372 .0000 .0037 .0248 .0000 .0297 .0000 .0050 .0000 .0644 .0000 .0669 .0000 .0000 .0062 .0099 .0000 .0359 .0000 .0000 .0149 .0000 .0384 .0000 .0161 .0000 .0149 .0025 .0000 .0012 .0000 .0000 .0000 .0000 .2082 .1698 .0384 .0037 .0000 .0000 .0000 .0000 .0000 .0458	Pollen counts converted to proportions
.29 .35 .25 .24 .24 .33 .29 .29 .25 .27 .21 .33 .27 .29 .21 .30 .30 .28	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .21 .24 .24 .25 .25 .27 .27 .28 .29 .29 .29 .29 .30 .30 .33 .33 .35	Euclidian 'distances' sorted from smallest to largest
C11 C15 C04 C05 C09 C03 C10 C13 C18 C08 C14 C01 C07 C17 C16 C12 C06 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 140 cm	SITE AND SAMPLE DETAILS
0. 8. 0. 17. 0. 0. 0. 0. 16. 32. 16. 0. 8. 0. 0. 17. 0. 15. 0. 5. 0. 29. 0. 17. 0. 0. 11. 13. 0. 34. 0. 0. 2. 3. 42. 0. 7. 0. 10. 0. 0. 0. 0. 0. 0. 0. 91. 80. 11. 0. 0. 0. 0. 0. 0. 29.	Original pollen counts obtained from Appendix F
.0000 .0156 .0000 .0331 .0000 .0000 .0000 .0000 .0312 .0624 .0312 .0000 .0156 .0000 .0000 .0331 .0000 .0292 .0000 .0097 .0000 .0565 .0000 .0331 .0000 .0000 .0214 .0253 .0000 .0663 .0000 .0000 .0039 .0058 .0819 .0000 .0136 .0000 .0195 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1774 .1559 .0214 .0000 .0000 .0000 .0000 .0000 .0000 .0565	Pollen counts converted to proportions
.27 .35 .23 .22 .23 .32 .28 .28 .23 .25 .19 .32 .26 .28 .21 .28 .30 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .21 .22 .23 .23 .23 .25 .26 .27 .27 .28 .28 .28 .28 .30 .32 .32 .35	Euclidian 'distances' sorted from smallest to largest
C11 C15 C04 C09 C05 C03 C10 C13 C18 C01 C08 C14 C07 C16 C17 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 145 cm	SITE AND SAMPLE DETAILS
0. 21. 2. 32. 0. 3. 0. 2. 27. 44. 17. 0. 21. 0. 0. 27. 0. 12. 0. 9. 0. 61. 0. 36. 0. 0. 12. 38. 0. 29. 7. 0. 8. 0. 29. 0. 14. 0. 8. 7. 0. 0. 0. 8. 0. 0. 153. 127. 26. 0. 0. 0. 0. 2. 0. 45.	Original pollen counts obtained from Appendix F
.0000 .0254 .0024 .0387 .0000 .0036 .0000 .0024 .0326 .0532 .0206 .0000 .0254 .0000 .0000 .0326 .0000 .0145 .0000 .0109 .0000 .0738 .0000 .0435 .0000 .0000 .0145 .0459 .0000 .0351 .0085 .0000 .0097 .0000 .0351 .0000 .0169 .0000 .0097 .0085 .0000 .0000 .0000 .0097 .0000 .0000 .1850 .1536 .0314 .0000 .0000 .0000 .0000 .0024 .0000 .0544	Pollen counts converted to proportions
.26 .37 .22 .22 .22 .32 .29 .28 .24 .25 .21 .33 .25 .27 .23 .29 .30 .28	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.21 .22 .22 .22 .23 .24 .25 .25 .26 .27 .28 .28 .29 .29 .30 .32 .33 .37	Euclidian 'distances' sorted from smallest to largest
C11 C03 C04 C05 C15 C09 C13 C10 C01 C14 C18 C08 C16 C07 C17 C06 C12 C02	Reference numbers of the corresponding modern sites

Site: MBS Depth 150 cm	SITE AND SAMPLE DETAILS
0. 12. 1. 25. 0. 0. 0. 0. 16. 35. 19. 0. 30. 0. 0. 12. 0. 24. 0. 8. 0. 31. 0. 21. 0. 0. 8. 15. 0. 37. 4. 0. 3. 0. 10. 0. 6. 0. 1. 11. 0. 0. 0. 0. 0. 0. 82. 67. 15. 1. 0. 0. 0. 3. 0. 17.	Original pollen counts obtained from Appendix F
.0000 .0233 .0019 .0486 .0000 .0000 .0000 .0000 .0311 .0681 .0370 .0000 .0584 .0000 .0000 .0233 .0000 .0467 .0000 .0156 .0000 .0603 .0000 .0409 .0000 .0000 .0156 .0292 .0000 .0720 .0078 .0000 .0058 .0000 .0195 .0000 .0117 .0000 .0019 .0214 .0000 .0000 .0000 .0000 .0000 .0000 .1595 .1304 .0292 .0019 .0000 .0000 .0000 .0058 .0000 .0331	Pollen counts converted to proportions
.25 .34 .21 .22 .22 .30 .26 .25 .22 .23 .20 .30 .23 .26 .21 .29 .27 .22	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .21 .21 .22 .22 .22 .22 .23 .23 .25 .25 .26 .26 .27 .29 .30 .30 .34	Euclidian 'distances' sorted from smallest to largest
C11 C03 C15 C04 C09 C05 C18 C10 C13 C01 C08 C14 C07 C17 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: MBS Depth 188 cm	**SITE AND SAMPLE DETAILS**
0. 21. 0. 28. 0. 0. 0. 0. 24. 61. 37. 0. 22. 0. 0. 15. 0. 10. 0. 12. 0. 16. 0. 0. 0. 0. 0. 11. 0. 0. 2. 0. 0. 4. 0. 0. 19. 0. 33. 2. 0. 0. 0. 9. 0. 0. 128. 118. 10. 0. 0. 0. 0. 1. 0. 18.	Original pollen counts obtained from Appendix F
.0000 .0349 .0000 .0466 .0000 .0000 .0000 .0000 .0399 .1015 .0616 .0000 .0366 .0000 .0000 .0250 .0000 .0166 .0000 .0200 .0000 .0266 .0000 .0000 .0000 .0000 .0000 .0183 .0000 .0000 .0033 .0000 .0000 .0067 .0000 .0000 .0316 .0000 .0549 .0033 .0000 .0000 .0000 .0150 .0000 .0000 .2130 .1963 .0166 .0000 .0000 .0000 .0000 .0017 .0000 .0300	Pollen counts converted to proportions
.31 .38 .26 .25 .25 .30 .26 .26 .23 .27 .19 .29 .27 .31 .23 .32 .27 .28	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .23 .23 .25 .25 .26 .26 .26 .27 .27 .27 .28 .29 .30 .31 .31 .32 .38	Euclidian 'distances' sorted from smallest to largest
C11 C09 C15 C04 C05 C08 C03 C07 C10 C13 C17 C18 C12 C06 C14 C01 C16 C02	Reference numbers of the corresponding modern sites
Site: SPC Depth 25 cm	**SITE AND SAMPLE DETAILS**
0. 13. 0. 11. 0. 1. 1. 3. 22. 79. 57. 0. 8. 2. 3. 9. 0. 45. 0. 14. 3. 0. 7. 19. 0. 0. 13. 18. 0. 13. 3. 0. 3. 3. 0. 0. 0. 5. 22. 0. 0. 0. 3. 2. 0. 0. 26. 11. 15. 4. 0. 0. 0. 0. 4. 13.	Original pollen counts obtained from Appendix F
.0000 .0286 .0000 .0242 .0000 .0022 .0022 .0066 .0484 .1736 .1253 .0000 .0176 .0044 .0066 .0198 .0000 .0989 .0000 .0308 .0066 .0000 .0154 .0418 .0000 .0000 .0286 .0396 .0000 .0286 .0066 .0000 .0066 .0066 .0000 .0000 .0000 .0110 .0484 .0000 .0000 .0000 .0066 .0044 .0000 .0000 .0571 .0242 .0330 .0088 .0000 .0000 .0000 .0000 .0088 .0286	Pollen counts converted to proportions
.27 .37 .23 .26 .23 .19 .14 .13 .17 .15 .19 .19 .23 .28 .29 .30 .15 .11	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.11 .13 .14 .15 .15 .17 .19 .19 .19 .23 .23 .23 .26 .27 .28 .29 .30 .37	Euclidian 'distances' sorted from smallest to largest
C18 C08 C07 C17 C10 C09 C06 C12 C11 C13 C03 C05 C04 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: SPC Depth 31 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 21. 0. 5. 4. 0. 10. 37. 27. 0. 12. 1. 0. 8. 0. 154. 0. 8. 1. 5. 3. 59. 2. 0. 8. 13. 0. 43. 6. 0. 6. 4. 0. 0. 9. 12. 7. 3. 0. 0. 3. 5. 0. 0. 61. 53. 8. 0. 5. 0. 0. 3. 21. 7.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0331 .0000 .0079 .0063 .0000 .0158 .0584 .0426 .0000 .0189 .0016 .0000 .0126 .0000 .2429 .0000 .0126 .0016 .0079 .0047 .0931 .0032 .0000 .0126 .0205 .0000 .0678 .0095 .0000 .0095 .0063 .0000 .0000 .0142 .0189 .0110 .0047 .0000 .0000 .0047 .0079 .0000 .0000 .0962 .0836 .0126 .0000 .0079 .0000 .0000 .0047 .0331 .0110	Pollen counts converted to proportions
.34 .22 .33 .35 .33 .36 .34 .33 .33 .33 .30 .38 .31 .34 .21 .38 .34 .20	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.20 .21 .22 .30 .31 .33 .33 .33 .33 .33 .34 .34 .34 .34 .35 .36 .38 .38	Euclidian 'distances' sorted from smallest to largest
C18 C15 C02 C11 C13 C10 C08 C09 C03 C05 C01 C14 C07 C17 C04 C06 C12 C16	Reference numbers of the corresponding modern sites
Site: SPC Depth 37 cm	**SITE AND SAMPLE DETAILS**
0. 0. 0. 13. 0. 0. 8. 18. 26. 49. 23. 0. 12. 0. 0. 4. 0. 137. 0. 6. 9. 16. 0. 18. 0. 0. 14. 11. 0. 18. 5. 0. 11. 5. 43. 0. 0. 5. 25. 2. 0. 0. 0. 19. 0. 0. 150. 93. 57. 0. 3. 0. 0. 0. 6. 12.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0159 .0000 .0000 .0098 .0220 .0318 .0599 .0281 .0000 .0147 .0000 .0000 .0049 .0000 .1675 .0000 .0073 .0110 .0196 .0000 .0220 .0000 .0000 .0171 .0134 .0000 .0220 .0061 .0000 .0134 .0061 .0526 .0000 .0000 .0061 .0306 .0024 .0000 .0000 .0000 .0232 .0000 .0000 .1834 .1137 .0697 .0000 .0037 .0000 .0000 .0000 .0073 .0147	Pollen counts converted to proportions
.32 .21 .28 .29 .29 .33 .31 .31 .29 .29 .23 .34 .28 .32 .14 .35 .31 .23	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .21 .23 .23 .28 .28 .29 .29 .29 .29 .31 .31 .31 .32 .32 .33 .34 .35	Euclidian 'distances' sorted from smallest to largest
C15 C02 C11 C18 C03 C13 C09 C05 C10 C04 C08 C07 C17 C14 C01 C06 C12 C16	Reference numbers of the corresponding modern sites
Site: SPC Depth 49 cm	**SITE AND SAMPLE DETAILS**
0. 5. 0. 35. 0. 0. 0. 0. 7. 45. 38. 0. 27. 1. 0. 18. 0. 111. 0. 0. 0. 6. 0. 13. 0. 0. 3. 29. 0. 17. 0. 0. 3. 0. 0. 0. 0. 6. 14. 0. 0. 0. 0. 0. 0. 0. 103. 76. 27. 1. 8. 0. 0. 0. 7. 13.	Original pollen counts obtained from Appendix F
.0000 .0082 .0000 .0571 .0000 .0000 .0000 .0000 .0114 .0734 .0620 .0000 .0440 .0016 .0000 .0294 .0000 .1811 .0000 .0000 .0000 .0098 .0000 .0212 .0000 .0000 .0049 .0473 .0000 .0277 .0000 .0000 .0049 .0000 .0000 .0000 .0000 .0098 .0228 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1680 .1240 .0440 .0016 .0131 .0000 .0000 .0000 .0114 .0212	Pollen counts converted to proportions
.31 .23 .29 .30 .28 .33 .29 .29 .27 .29 .24 .33 .28 .31 .16 .34 .29 .21	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.16 .21 .23 .24 .27 .28 .28 .29 .29 .29 .29 .29 .30 .31 .31 .33 .33 .34	Euclidian 'distances' sorted from smallest to largest
C15 C18 C02 C11 C09 C13 C05 C10 C03 C08 C07 C17 C04 C14 C01 C12 C06 C16	Reference numbers of the corresponding modern sites

Site: SPC Depth 56 cm	SITE AND SAMPLE DETAILS
0. 0. 3. 15. 0. 0. 0. 0. 14. 87. 73. 0. 47. 18. 0. 36. 0. 53. 0. 3. 1. 24. 5. 44. 4. 0. 9. 16. 0. 17. 12. 0. 7. 5. 14. 0. 10. 0. 18. 7. 0. 0. 3. 0. 0. 0. 55. 45. 10. 6. 12. 0. 0. 0. 25. 27.	Original pollen counts obtained from Appendix F
.0000 .0000 .0041 .0207 .0000 .0000 .0000 .0000 .0193 .1200 .1007 .0000 .0648 .0248 .0000 .0497 .0000 .0731 .0000 .0041 .0014 .0331 .0069 .0607 .0055 .0000 .0124 .0221 .0000 .0234 .0166 .0000 .0097 .0069 .0193 .0000 .0138 .0000 .0248 .0097 .0000 .0000 .0041 .0000 .0000 .0000 .0759 .0621 .0138 .0083 .0166 .0000 .0000 .0000 .0345 .0372	Pollen counts converted to proportions
.24 .36 .20 .23 .20 .24 .18 .17 .16 .16 .18 .24 .20 .24 .26 .26 .20 .14	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.14 .16 .16 .17 .18 .18 .20 .20 .20 .20 .23 .24 .24 .24 .24 .26 .26 .36	Euclidian 'distances' sorted from smallest to largest
C18 C10 C09 C08 C11 C07 C17 C13 C03 C05 C04 C12 C01 C06 C14 C15 C16 C02	Reference numbers of the corresponding modern sites
Site: SPC Depth 65 cm	**SITE AND SAMPLE DETAILS**
0. 2. 2. 7. 0. 0. 7. 0. 37. 134. 97. 0. 21. 13. 0. 28. 0. 13. 0. 0. 0. 12. 12. 48. 10. 0. 6. 39. 0. 48. 8. 0. 12. 3. 2. 0. 18. 0. 37. 2. 0. 0. 4. 0. 0. 0. 66. 61. 5. 10. 3. 0. 0. 14. 17. 47.	Original pollen counts obtained from Appendix F
.0000 .0024 .0024 .0083 .0000 .0000 .0083 .0000 .0438 .1586 .1148 .0000 .0249 .0154 .0000 .0331 .0000 .0154 .0000 .0000 .0000 .0142 .0142 .0568 .0118 .0000 .0071 .0462 .0000 .0568 .0095 .0000 .0142 .0036 .0024 .0000 .0213 .0000 .0438 .0024 .0000 .0000 .0047 .0000 .0000 .0000 .0781 .0722 .0059 .0118 .0036 .0000 .0000 .0166 .0201 .0556	Pollen counts converted to proportions
.23 .42 .20 .22 .18 .18 .14 .14 .13 .14 .18 .20 .21 .25 .31 .25 .16 .17	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .14 .14 .14 .16 .17 .18 .18 .18 .20 .20 .21 .22 .23 .25 .25 .31 .42	Euclidian 'distances' sorted from smallest to largest
C09 C08 C10 C07 C17 C18 C11 C05 C06 C03 C12 C13 C04 C01 C16 C14 C15 C02	Reference numbers of the corresponding modern sites
Site: SPC Depth 70 cm	**SITE AND SAMPLE DETAILS**
0. 0. 3. 3. 0. 0. 0. 0. 27. 109. 82. 0. 33. 7. 0. 12. 0. 11. 0. 2. 0. 19. 3. 7. 2. 0. 6. 29. 0. 73. 0. 0. 8. 7. 3. 0. 4. 0. 28. 4. 0. 0. 5. 5. 0. 0. 90. 87. 3. 2. 0. 0. 0. 13. 13. 20.	Original pollen counts obtained from Appendix F
.0000 .0000 .0042 .0042 .0000 .0000 .0000 .0000 .0375 .1514 .1139 .0000 .0458 .0097 .0000 .0167 .0000 .0153 .0000 .0028 .0000 .0264 .0042 .0097 .0028 .0000 .0083 .0403 .0000 .1014 .0000 .0000 .0111 .0097 .0042 .0000 .0056 .0000 .0389 .0056 .0000 .0000 .0069 .0069 .0000 .0000 .1250 .1208 .0042 .0028 .0000 .0000 .0000 .0181 .0181 .0278	Pollen counts converted to proportions
.26 .41 .20 .19 .22 .21 .17 .19 .12 .16 .15 .22 .23 .27 .28 .29 .18 .20	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.12 .15 .16 .17 .18 .19 .19 .20 .20 .21 .22 .22 .23 .26 .27 .28 .29 .41	Euclidian 'distances' sorted from smallest to largest
C09 C11 C10 C07 C17 C08 C04 C03 C18 C06 C12 C05 C13 C01 C14 C15 C16 C02	Reference numbers of the corresponding modern sites

Site: SPC Depth 81 cm	SITE AND SAMPLE DETAILS
0. 0. 0. 11. 0. 0. 5. 0. 11. 59. 48. 0. 12. 0. 0. 4. 0. 6. 0. 0. 0. 8. 0. 36. 1. 0. 15. 45. 0. 19. 3. 0. 3. 2. 0. 0. 6. 0. 5. 0. 0. 0. 3. 12. 0. 0. 117. 99. 18. 11. 0. 0. 0. 5. 6. 18.	Original pollen counts obtained from Appendix F
.0000 .0000 .0000 .0187 .0000 .0000 .0085 .0000 .0187 .1003 .0816 .0000 .0204 .0000 .0000 .0068 .0000 .0102 .0000 .0000 .0000 .0136 .0000 .0612 .0017 .0000 .0255 .0765 .0000 .0323 .0051 .0000 .0051 .0034 .0000 .0000 .0102 .0000 .0085 .0000 .0000 .0000 .0051 .0204 .0000 .0000 .1990 .1684 .0306 .0187 .0000 .0000 .0000 .0085 .0102 .0306	Pollen counts converted to proportions
.28 .39 .25 .25 .24 .29 .25 .24 .22 .24 .19 .28 .26 .28 .26 .31 .25 .27	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.19 .22 .24 .24 .24 .25 .25 .25 .25 .26 .26 .27 .28 .28 .28 .29 .31 .39	Euclidian 'distances' sorted from smallest to largest
C11 C09 C05 C10 C08 C07 C04 C17 C03 C13 C15 C18 C12 C14 C01 C06 C16 C02	Reference numbers of the corresponding modern sites
Site: SPC Depth 91 cm	**SITE AND SAMPLE DETAILS**
0. 16. 3. 15. 0. 0. 0. 0. 17. 130. 113. 0. 22. 3. 0. 11. 0. 27. 0. 9. 0. 3. 0. 12. 2. 0. 31. 12. 0. 31. 7. 0. 0. 6. 0. 0. 12. 0. 22. 0. 0. 0. 0. 2. 0. 0. 133. 127. 6. 7. 0. 0. 0. 8. 5. 58.	Original pollen counts obtained from Appendix F
.0000 .0188 .0035 .0176 .0000 .0000 .0000 .0000 .0200 .1529 .1329 .0000 .0259 .0035 .0000 .0129 .0000 .0318 .0000 .0106 .0000 .0035 .0000 .0141 .0024 .0000 .0365 .0141 .0000 .0365 .0082 .0000 .0000 .0071 .0000 .0000 .0141 .0000 .0259 .0000 .0000 .0000 .0000 .0024 .0000 .0000 .1565 .1494 .0071 .0082 .0000 .0000 .0000 .0094 .0059 .0682	Pollen counts converted to proportions
.27 .39 .24 .23 .20 .22 .16 .18 .14 .18 .13 .19 .26 .28 .26 .26 .17 .22	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .14 .16 .17 .18 .18 .19 .20 .22 .22 .23 .24 .26 .26 .26 .27 .28 .39	Euclidian 'distances' sorted from smallest to largest
C11 C09 C07 C17 C08 C10 C12 C05 C18 C06 C04 C03 C13 C15 C16 C01 C14 C02	Reference numbers of the corresponding modern sites
Site: SPC Depth 97 cm	**SITE AND SAMPLE DETAILS**
0. 10. 0. 37. 0. 0. 0. 0. 5. 134. 129. 0. 10. 1. 0. 5. 0. 14. 0. 11. 0. 5. 0. 17. 0. 0. 17. 21. 0. 43. 7. 0. 2. 0. 0. 0. 10. 0. 15. 1. 0. 0. 0. 7. 0. 0. 111. 98. 13. 0. 0. 0. 0. 4. 3. 19.	Original pollen counts obtained from Appendix F
.0000 .0134 .0000 .0494 .0000 .0000 .0000 .0000 .0067 .1789 .1722 .0000 .0134 .0013 .0000 .0067 .0000 .0187 .0000 .0147 .0000 .0067 .0000 .0227 .0000 .0000 .0227 .0280 .0000 .0574 .0093 .0000 .0027 .0000 .0000 .0000 .0134 .0000 .0200 .0013 .0000 .0000 .0000 .0093 .0000 .0000 .1482 .1308 .0174 .0000 .0000 .0000 .0000 .0053 .0040 .0254	Pollen counts converted to proportions
.29 .42 .25 .23 .25 .22 .13 .17 .12 .17 .13 .17 .27 .30 .30 .30 .13 .22	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.12 .13 .13 .13 .17 .17 .17 .22 .22 .23 .25 .25 .27 .29 .30 .30 .30 .42	Euclidian 'distances' sorted from smallest to largest
C09 C11 C07 C17 C12 C08 C10 C18 C06 C04 C03 C05 C13 C01 C15 C14 C16 C02	Reference numbers of the corresponding modern sites

Site: SPC Depth 107 cm	SITE AND SAMPLE DETAILS
0. 17. 0. 4. 0. 7. 0. 0. 12. 129. 117. 0. 18. 4. 0. 8. 0. 9. 0. 21. 0. 6. 0. 11. 0. 0. 22. 36. 0. 12. 8. 0. 0. 3. 4. 0. 19. 0. 21. 3. 0. 0. 4. 17. 0. 0. 159. 143. 16. 5. 0. 0. 0. 3. 4. 48.	Original pollen counts obtained from Appendix F
.0000 .0191 .0000 .0045 .0000 .0079 .0000 .0000 .0135 .1449 .1315 .0000 .0202 .0045 .0000 .0090 .0000 .0101 .0000 .0236 .0000 .0067 .0000 .0124 .0000 .0000 .0247 .0404 .0000 .0135 .0090 .0000 .0000 .0034 .0045 .0000 .0213 .0000 .0236 .0034 .0000 .0000 .0045 .0191 .0000 .0000 .1787 .1607 .0180 .0056 .0000 .0000 .0000 .0034 .0045 .0539	Pollen counts converted to proportions
.29 .40 .25 .23 .22 .24 .18 .19 .16 .20 .13 .20 .26 .29 .27 .28 .18 .25	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.13 .16 .18 .18 .19 .20 .20 .22 .23 .24 .25 .25 .26 .27 .28 .29 .29 .40	Euclidian 'distances' sorted from smallest to largest
C11 C09 C07 C17 C08 C10 C12 C05 C04 C06 C18 C03 C13 C15 C16 C01 C14 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 138	**SITE AND SAMPLE DETAILS**
0. 0. 0. 7. 0. 0. 0. 0. 2. 13. 11. 0. 37. 0. 0. 25. 0. 0. 0. 0. 0. 0. 0. 16. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 10. 0. 0. 0. 0. 0. 0. 0. 61. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.4313 .0000 .0000 .0000 .0219 .0000 .0000 .0000 .0000 .0063 .0406 .0344 .0000 .1156 .0000 .0000 .0781 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0500 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0313 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1906 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.53 .61 .54 .56 .54 .58 .56 .55 .54 .54 .53 .58 .52 .54 .55 .57 .55 .54	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.52 .53 .53 .54 .54 .54 .54 .54 .54 .55 .55 .55 .56 .56 .57 .58 .58 .61	Euclidian 'distances' sorted from smallest to largest
C13 C01 C11 C03 C18 C14 C10 C09 C05 C08 C15 C17 C04 C07 C16 C12 C06 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 142	**SITE AND SAMPLE DETAILS**
0. 0. 0. 27. 0. 0. 0. 0. 4. 8. 4. 0. 31. 0. 0. 18. 0. 0. 0. 0. 0. 0. 0. 13. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 6. 0. 0. 0. 0. 0. 0. 0. 29. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.5035 .0000 .0000 .0000 .0957 .0000 .0000 .0000 .0000 .0142 .0284 .0142 .0000 .1099 .0000 .0000 .0638 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0461 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0213 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1028 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.58 .67 .58 .61 .59 .62 .61 .59 .60 .59 .59 .62 .57 .59 .61 .62 .60 .58	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.57 .58 .58 .58 .59 .59 .59 .59 .59 .60 .60 .61 .61 .61 .62 .62 .62 .67	Euclidian 'distances' sorted from smallest to largest
C13 C01 C03 C18 C10 C05 C14 C11 C08 C09 C17 C07 C04 C15 C16 C06 C12 C02	Reference numbers of the corresponding modern sites

Site: EBC Sample DMS 144	SITE AND SAMPLE DETAILS
0. 0. 0. 32. 0. 0. 0. 0. 18. 29. 11. 0. 9. 0. 0. 8. 0. 0. 0. 0. 0. 0. 0. 14. 0. 0. 0. 0. 0. 0. 0. 0. 0. 2. 0. 0. 6. 0. 0. 0. 0. 0. 8. 0. 0. 0. 102. 0. 0. 0. 0. 0. 0. 1. 0.	Original pollen counts obtained from Appendix F
.3750 .0000 .0000 .0000 .0833 .0000 .0000 .0000 .0000 .0469 .0755 .0286 .0000 .0234 .0000 .0000 .0208 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0365 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0052 .0000 .0000 .0156 .0000 .0000 .0000 .0000 .0000 .0208 .0000 .0000 .0000 .2656 .0000 .0000 .0000 .0000 .0000 .0000 .0026 .0000	Pollen counts converted to proportions
.51 .58 .49 .50 .50 .53 .50 .50 .48 .50 .47 .52 .49 .51 .50 .53 .49 .50	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.47 .48 .49 .49 .49 .50 .50 .50 .50 .50 .50 .50 .51 .51 .52 .53 .53 .58	Euclidian 'distances' sorted from smallest to largest
C11 C09 C13 C17 C03 C10 C18 C08 C15 C04 C07 C05 C14 C01 C12 C06 C16 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 147	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 17. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 5. 0. 0. 0. 0. 0. 0. 0. 0. 0. 11. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.8167 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0944 .0000 .0278 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0611 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.85 .92 .86 .88 .86 .89 .88 .87 .88 .86 .87 .89 .85 .86 .88 .89 .87 .86	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.85 .85 .86 .86 .86 .86 .86 .87 .87 .87 .88 .88 .88 .88 .89 .89 .89 .92	Euclidian 'distances' sorted from smallest to largest
C13 C01 C03 C18 C05 C14 C10 C08 C17 C11 C09 C04 C07 C15 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 149	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 43. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 19. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.7062 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2038 .0000 .0900 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.77 .84 .77 .80 .78 .81 .80 .79 .79 .78 .79 .82 .77 .78 .80 .81 .79 .78	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.77 .77 .77 .78 .78 .78 .78 .79 .79 .79 .79 .80 .80 .80 .81 .81 .82 .84	Euclidian 'distances' sorted from smallest to largest
C13 C01 C03 C18 C05 C14 C10 C11 C08 C17 C09 C15 C04 C07 C16 C06 C12 C02	Reference numbers of the corresponding modern sites

Site: EBC Sample DMS 150	SITE AND SAMPLE DETAILS
0. 0. 0. 7. 0. 0. 0. 0. 0. 0. 0. 0. 27. 0. 0. 11. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 30. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.6667 .0000 .0000 .0000 .0311 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .1200 .0000 .0000 .0489 .0000 .1333 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.72 .79 .73 .75 .73 .76 .75 .74 .74 .74 .74 .77 .72 .73 .75 .76 .74 .73	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.72 .72 .73 .73 .73 .73 .74 .74 .74 .74 .74 .75 .75 .75 .76 .76 .77 .79	Euclidian 'distances' sorted from smallest to largest
C13 C01 C03 C18 C05 C14 C10 C11 C08 C09 C17 C15 C04 C07 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 87	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 16. 22. 6. 0. 45. 0. 0. 13. 0. 0. 0. 0. 0. 0. 0. 0. 3. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 15. 0. 0. 0. 93. 0. 0. 9. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.2806 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0516 .0710 .0194 .0000 .1452 .0000 .0000 .0419 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0097 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0032 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0484 .0000 .0000 .0000 .3000 .0000 .0000 .0290 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.47 .55 .46 .47 .47 .49 .47 .46 .45 .46 .43 .49 .46 .48 .46 .50 .46 .47	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.43 .45 .46 .46 .46 .46 .46 .46 .47 .47 .47 .47 .47 .48 .49 .49 .50 .55	Euclidian 'distances' sorted from smallest to largest
C11 C09 C13 C03 C10 C15 C08 C17 C18 C04 C07 C01 C05 C14 C12 C06 C16 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 88	**SITE AND SAMPLE DETAILS**
88. 0. 0. 0. 3. 0. 0. 0. 0. 62. 111. 49. 0. 22. 0. 0. 9. 6. 0. 0. 0. 0. 0. 13. 1. 3. 0. 0. 0. 0. 0. 0. 0. 8. 29. 0. 0. 24. 0. 1. 0. 0. 0. 25. 9. 0. 0. 245. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.1243 .0000 .0000 .0000 .0042 .0000 .0000 .0000 .0000 .0876 .1568 .0692 .0000 .0311 .0000 .0000 .0127 .0085 .0000 .0000 .0000 .0000 .0000 .0184 .0014 .0042 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0113 .0410 .0000 .0000 .0339 .0000 .0014 .0000 .0000 .0000 .0353 .0127 .0000 .0000 .3460 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.44 .49 .41 .39 .42 .42 .38 .38 .35 .38 .33 .40 .41 .43 .40 .44 .37 .40	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.33 .35 .37 .38 .38 .38 .39 .40 .40 .40 .41 .41 .42 .42 .43 .44 .44 .49	Euclidian 'distances' sorted from smallest to largest
C11 C09 C17 C07 C08 C10 C04 C15 C12 C18 C03 C13 C06 C05 C14 C01 C16 C02	Reference numbers of the corresponding modern sites

Site: EBC Sample DMS 119	SITE AND SAMPLE DETAILS
0. 0. 0. 19. 0. 0. 0. 0. 0. 11. 11. 0. 13. 0. 0. 38. 0. 0. 0. 0. 0. 0. 0. 13. 0. 0. 0. 0. 6. 0. 0. 0. 0. 0. 0. 23. 7. 0. 0. 5. 0. 0. 14. 0. 0. 0. 31. 0. 0. 2. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.3814 .0000 .0000 .0000 .0609 .0000 .0000 .0000 .0000 .0000 .0353 .0353 .0000 .0417 .0000 .0000 .1218 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0417 .0000 .0000 .0000 .0000 .0192 .0000 .0000 .0000 .0000 .0000 .0000 .0737 .0224 .0000 .0000 .0160 .0000 .0000 .0449 .0000 .0000 .0000 .0994 .0000 .0000 .0064 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.48 .58 .49 .52 .50 .54 .51 .50 .50 .49 .50 .54 .47 .49 .52 .53 .51 .49	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.47 .48 .49 .49 .49 .49 .50 .50 .50 .50 .51 .51 .52 .52 .53 .54 .54 .58	Euclidian 'distances' sorted from smallest to largest
C13 C01 C18 C03 C10 C14 C05 C08 C11 C09 C17 C07 C04 C15 C16 C06 C12 C02	Reference numbers of the corresponding modern sites
Site: EBC Sample DMS 120	**SITE AND SAMPLE DETAILS**
0. 0. 0. 0. 0. 0. 0. 0. 0. 97. 97. 0. 41. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 17. 0. 0. 0. 0. 0. 0. 0. 0.	Original pollen counts obtained from Appendix F
.3226 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .2608 .2608 .0000 .1102 .0000 .0457 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000	Pollen counts converted to proportions
.53 .64 .54 .55 .55 .56 .51 .51 .51 .51 .52 .52 .53 .55 .58 .56 .50 .51	Euclidian 'distance' of this spectrum to each of the 18 modern sites
.50 .51 .51 .51 .51 .51 .52 .52 .53 .53 .54 .55 .55 .55 .56 .56 .58 .64	Euclidian 'distances' sorted from smallest to largest
C17 C10 C07 C08 C09 C18 C11 C12 C13 C01 C03 C05 C04 C14 C06 C16 C15 C02	Reference numbers of the corresponding modern sites

GLOSSARY OF ABBREVIATIONS

AD (years)	*Anno Domini* = Calendar years of the Christian era
BP (years)	Before present, ie before 1950, the base date for radiocarbon
CSIR	Council for Scientific and Industrial Research
CTCP	Cape Town Collection of Pollen
EBC	Elands Bay Cave
ECODES	Ecological codes used for grouping the Sandveld pollen data
FRD	Foundation for Research and Development
GCMs	General Circulation Models
GDN	Northern borehole on Grootdrift Farm
GDS	Southern borehole on Grootdrift Farm
GDV1&2	Grootdrift vibracores 1 and 2
GDV4	Grootdrift vibracore 4
GPS	Global Positioning System
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
KFN	Klaarfontein
MBS	Muisbosskerm
NBI	National Botanical Institute
NNIs	Nearest Neighbour Indices (measure of Euclidian distance)
PAGES	Past Global Changes
pH	A measure of hydrogen ion concentration
SARU	Spatial Archaeology Research Unit
SPC	Spring Cave
Spp.	Species
SSTs	Sea Surface Temperatures
UCT	University of Cape Town
UPE	University of Port Elizabeth
WCP	West Coast Pollen